Assessment of the Aquatic Effects of Mining in Canada:

AQUAMIN

Supporting Document II:

Regional Syntheses

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Assessment of the Aquatic Effects of Mining in Canada: AQUAMIN

Supporting Document II:

Regional Syntheses

Prepared for:
AQUAMIN Steering Group

By:
AQUAMIN Working Groups 3, 4, 5, and 6
AQUAMIN Secretariat

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1 Introduction

1.1 Overview

Canada's *Metal Mining Liquid Effluent Regulations* (MMLER) were promulgated in 1977 as part of the *Fisheries Act*. In 1990, Canada's *Green Plan* directed that:

> *"Pollution prevention regulations contained in the* Fisheries Act *are being updated and strengthened, beginning with the* Pulp and Paper Regulations *and the* Metal Mining Liquid Effluent Regulations*."*

In 1992 Environment Canada sponsored a workshop to discuss the MMLER revision process, and to seek guidance on this process from representatives of all groups with a stake in mining and the environment. Stakeholder groups represented were: the Federal Government; the Mining Association of Canada; provincial governments of Newfoundland, Nova Scotia, New Brunswick, Quebec, Ontario, Manitoba and Saskatchewan; the Quebec Mining Association; Canada's Aboriginal Peoples; and Environmental Non-Government Organizations. A key recommendation of participants in this workshop was:

> *"Before any amendments [to the MMLER] are undertaken, the effectiveness of the current MMLER needs to be evaluated through an assessment of the impacts of metal mining effluent on the aquatic environment."*

The Assessment of the Aquatic Effects of Mining in Canada (AQUAMIN) was initiated on the basis of this recommendation.

1.2 Objective of AQUAMIN

The objective of AQUAMIN was to examine the effectiveness of the MMLER. This objective was realized by assessing existing information on the effects of metal mining on aquatic ecosystems in Canada. The AQUAMIN Steering Group recommended that the study focus on the effects of mine effluents on freshwater environments. Accordingly, with two exceptions, mines included in the review were limited to those that discharge effluents into such environments.

The findings of AQUAMIN provide the basis for the formulation of recommendations in three key areas:

- amendments to the MMLER
- the design of a national environmental effects monitoring program for metal mining
- information gaps and research needs

Recommendations are included in the Final Report and are to be considered by Environment Canada and the Department of Fisheries and Oceans in the regulatory review process.

1.3 Outline of the AQUAMIN Document

The deliverable from AQUAMIN a Final Report and two accompanying supporting documents.

1.3.1 Final Report

The Final Report was prepared by Working Groups 7 and 8. It provides a summary of key findings regarding the effects of mining on aquatic ecosystems in Canada, as documented in Supporting Document II. It also contains recommendations and supporting rationale regarding:

- a cooperative national environmental protection framework
- revisions to the MMLER
- site-specific requirements
- the design of a national environmental effects monitoring program for metal mining in Canada
- revisions to the Environmental Code of Practice for Mines
- information gaps and research needs

1.3.2 Supporting Document I

This document, prepared by Working Group 2 and the Secretariat, is divided into three sections.

Section I: Geology and Ore Deposits of Canada

An overview of the geology of Canada, for nongeologists, and a summary of the key characteristics of ore deposit types occurring in Canada are presented. This section also introduces some concepts of environmental geochemistry, including the oxidation of sulphide minerals in natural environments.

Section II: Metal Mining and Milling Processes

An overview of mining and milling processes from exploration to mine closure is presented. Effluent management and treatment technologies are also summarized.

Section III: The Regulatory Regime

A summary of federal and provincial environmental regulations for operating mines, and a comparison of federal regulations in Canada with those in other countries are presented.

1.3.3 Supporting Document II

This document, prepared by Working Groups 3, 4, 5, and 6, is based upon information drawn from a wide range of sources, including:

- reports completed for mining companies by consultants or company staff
- reports completed by government regulatory and research agencies
- articles from scientific journals
- conference proceedings

The cooperation of the Canadian mining industry in supplying reports for AQUAMIN was particularly valuable to the success of the assessment.

To complete Supporting Document II Canada was divided into four regions. For each region, a report on the aquatic effects of mining was prepared. These reports include case studies, regional syntheses of the case studies, and material from non-case study sites. This document is a compilation of the regional syntheses of these regions.

1.4 Preparation of Supporting Document II

Supporting Document II was prepared by four Working Groups which were divided geographically:

Working Group 3:	Appalachian Region (Newfoundland, Nova Scotia, and New Brunswick)
Working Group 4QUÉ:	Eastern Canadian Shield (Québec)
Working Group 4ONT:	Eastern Canadian Shield (Ontario)
Working Group 5:	Western Canadian Shield (Manitoba, Saskatchewan, and the Northwest Territories)
Working Group 6:	Western Cordillera (British Columbia and the Yukon)

Members of the Working Groups are listed in Appendix 1. The activities of all Working Groups were coordinated by the AQUAMIN Secretariat.

1.4.1 Collection of Information for AQUAMIN

To conduct AQUAMIN it was necessary to obtain as much information as possible. Various groups, including mining companies, the Mining Association of Canada, and Provincial agencies and Federal Government agencies across Canada were asked to submit relevant documents. All documents received by the AQUAMIN Secretariat were catalogued before they were submitted to an outside consultant who undertook the following:

1. Screened the scientific information provided by the AQUAMIN Secretariat (published and unpublished studies, journal articles, government reports, consultant reports, company reports, *etc.*) by using the screening criteria developed by WG1. Screening started with the most recent material. The quality of data and the information in each report were evaluated and assigned scores.

2. Brought questions, where uncertain of scoring on criteria, to the Secretariat.

3. Sorted the screened information by:
   - mine site and geologic region
   - type of effects (chemical, biological, physical)

   and cross-referenced the information.

4. Entered references in a database. Database entries included the keywords and the scores assigned by the consultant. The database was developed in consultation with the Secretariat and Working Group 1.

Once the database was developed each document could be assigned to a category or categories on the basis of the technical content (*i.e.*, topics in the Criteria Document). The documents were then divided by region and forwarded to Working Groups 3 to 6 for assessment. Each member of each Working Group was supplied with a diskette copy of the database. Over 700 references were entered into the database. It is recognized, however, that considerable data were not included in this review.

1.4.2 Criteria for Screening Information

Working Group 1 developed a Criteria Document that, after discussion and revision, was used as a guide for Working Groups 3 to 6 when reviewing information on the aquatic effects of mining. Working Group 1 separated the aquatic environment into the following topics:

- water chemistry
- sediment chemistry
- toxicity
- benthos
- zooplankton
- phytoplankton
- macrophytes
- shellfish
- fish
- vertebrates
- other

Where appropriate, each of these topics was subdivided to include laboratory work, field work, tissue residues or physiological indicators, and assessment of populations/communities. This Criteria Document also defines the various information categories that need to be included in any given document to ensure that the quality of the data is adequate. The categories were as follows:

Study or Experimental Design:

- Within-station Variation - is the spatial and temporal variation at the site considered?
- Number and Location of Sampling Sites does this consider the fate of contaminants; was the selection determined by pre-sampling; was the design optimized?
- Related Factors/Conditions other factors/environmental conditions reported; other information reported such as water quality, sediment quality, habitat description, flows, dilution; confounding factors such as other sources of pollution

Reference and Controls:

- Spatial Reference Site area not exposed to effluent, similar conditions/ habitat/ flows/ water chemistry/time
- Temporal Reference are historical data considered; background/baseline data, compared with previous studies?
- Negative Control - applies to toxicity test, no toxicant in test

Methods - Are the methods:

- Based on validated procedures prepared by a recognized agency: ASTM, USEPA, Environment Canada, *etc.*?
- Methods used in the literature?
- Is a very detailed description provided; is full documentation of all the steps provided so that this method could be repeated?

Quality Control:

- Detection Limits - provided
- Precision - standard deviation, coefficient of variation, replicates
- Accuracy - expressed as percentage of true value, reference to biological collections, method blanks, reference toxicity material

Data Analysis:

- Cause-Effect or Dose Response - are the toxicological data, contaminant data, and biological effects compared?
- Magnitude/Extent of Effects - described, toxicity end-point given, spatial extent of the contaminant concentration, population/community index
- Statistical Assessment - are statistics used to summarize the chemistry or compare historical data to a treatment; is a control compared with a treatment?

1.4.3 Preparation of Case Studies

For each region several case studies were prepared. The case studies are an important component of Supporting Document II and the Final Report. The goal of the case studies was to compile and analyse as much relevant information as possible for the selected sites. Through this site analysis, the effects on the receiving environment were identified and, where possible, the causes/sources of the effects were described. The case studies also assessed whether or not the monitoring conducted at the sites was adequate to identify and quantify environmental effects on the receiving environment. The goals of assessing the monitoring were to:

- identify gaps in monitoring that may affect the conclusions reached in the case studies
- provide guidance to Working Group 7, which prepared recommendations on the design of an environmental effects monitoring program

Mining companies at all case study sites were contacted, and in many cases, company representatives participated in the preparation and/or review of the case studies.

In total, 18 case studies were prepared for sites illustrated in Figure 1.

Figure 1: Case study sites

To assist the groups preparing the case studies, and to ensure the highest possible level of consistency in the preparation and format of case studies the chairs of the four Working Groups, together with the Steering Group and the Secretariat, developed a framework for examining the aquatic effects of metal mining activities, as well as a more detailed model for the assessment of case studies. The framework and model are summarized in figures 2 and 3, respectively. A key step in the framework was the Detailed Examination of Effects, the objective of which was to summarized the extent and magnitude of effects reported in each studied examined by the working groups. These sumaries, which are assembled in Report Review Compilation documents, guided Working Groups in the selection of case study sites, and were the basis for the preparation of case studies.

Factors which were considered in the selection of case study sites included the:

- type of mine (to represent different ore types)
- extent (spatial and temporal) and completeness (abiotic and biotic) of data available
- reliability of the data
- discharges of water to the receiving environment
- availability of background or baseline data

Figure 2: Framework for the examination of aquatic effects of metal mining activities

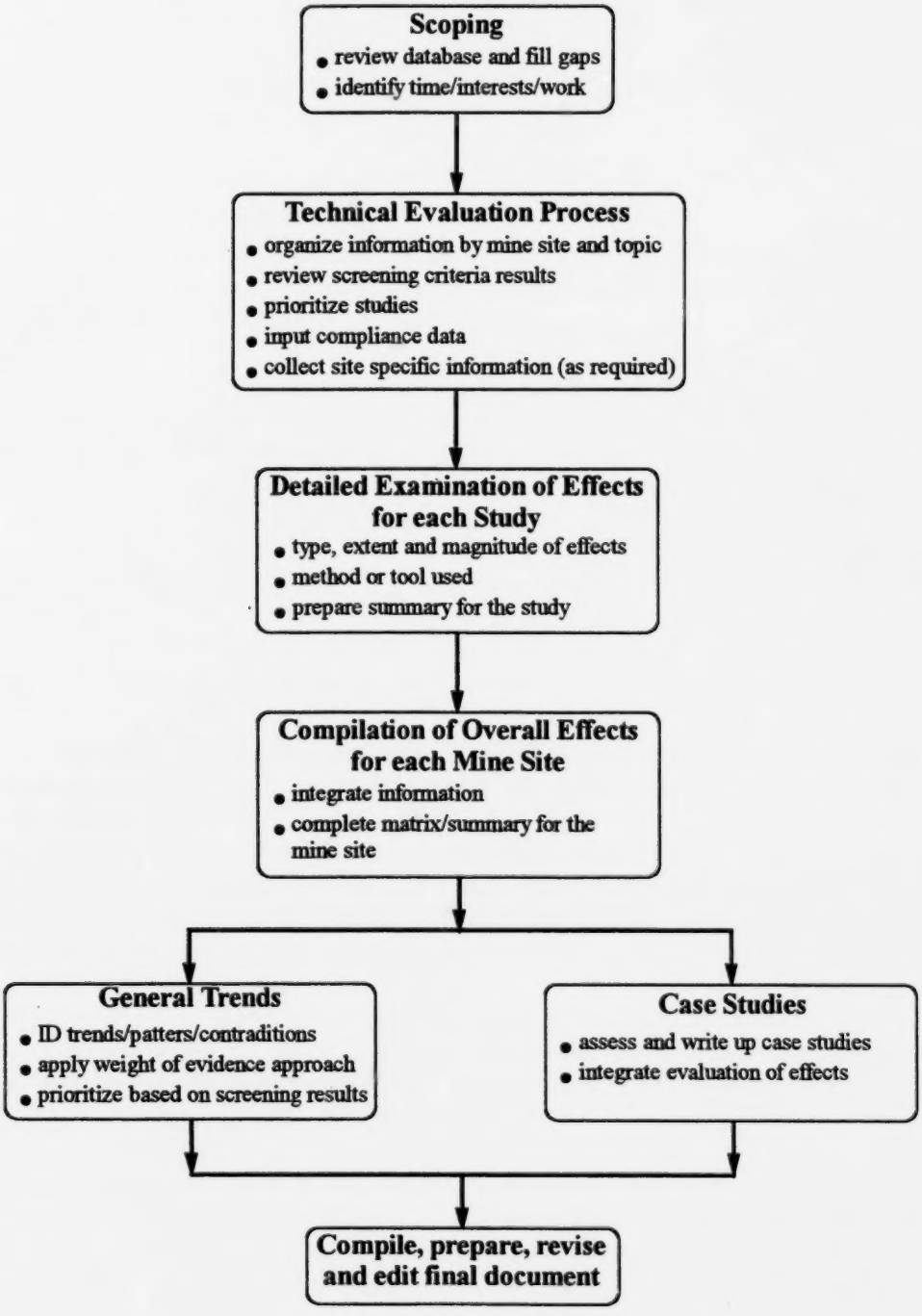
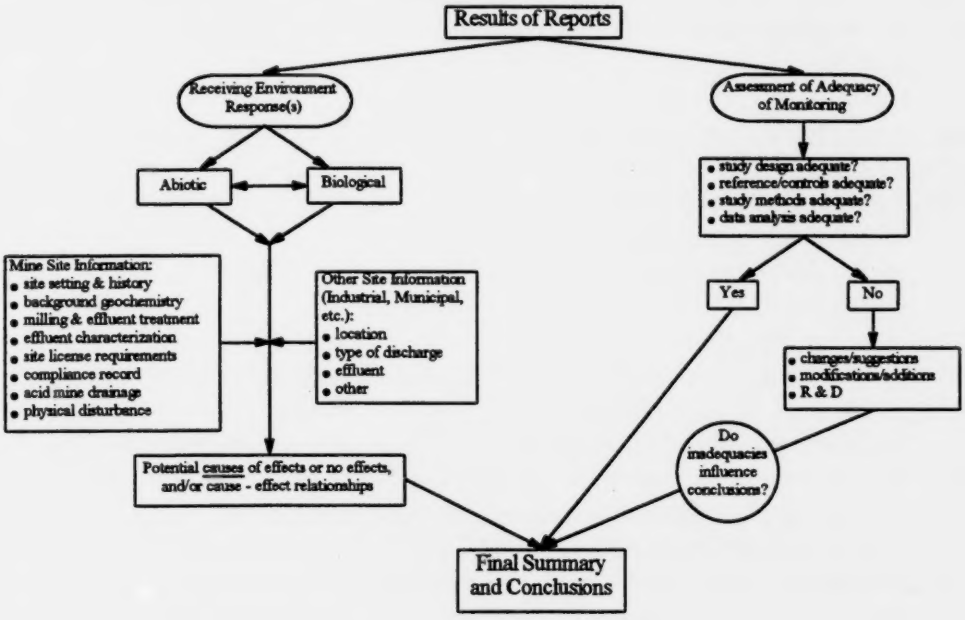

Scoping
• review database and fill gaps
• identify time/interests/work
Technical Evaluation Process
• organize information by mine site and topic
• review screening criteria results
• prioritize studies
• input compliance data
• collect site specific information (as required)
Detailed Examination of Effects for each Study
• type, extent and magnitude of effects
• method or tool used
• prepare summary for the study
Compilation of Overall Effects for each Mine Site
• integrate information
• complete matrix/summary for the mine site
General Trends
• ID trends/patters/contraditions
• apply weight of evidence approach
• prioritize based on screening results
Case Studies
• assess and write up case studies
• integrate evaluation of effects
Compile, prepare, revise and edit final document

Figure 3: Model for the assessment of case studies



Working Groups 3 and 6 prepared overviews of how their reports were prepared. These overviews are summarized in the following sections. More detailed descriptions are on file with the AQUAMIN Secretariat

1.4.4 Preparation of the Working Group 3 Report

- Appalachian Region contains a diverse cross-section of mining activities
- mining operations are few in number compared to the other regions of Canada but mining has a long history in this region
  - → many mining operations are currently closed or abandoned
- there is a paucity of environmental effects information available for many sites
- by contacting mining companies and government departments a considerable collection of information related to environmental monitoring was assembled for WG 3
- WG 3 members conducted assessments of aquatic effects on 16 mining operations and one smelter where aquatic effects information was available
- WG 3 did not evaluate information from coal mining or industrial mineral mining.
- WG 3 divided reports by mine site for examination. Each person was assigned a specific mine site or sites and was responsible for completing the assessment for those sites

- A regional overview was prepared which covered the following items that WG 3 members felt were important for a complete picture of the Appalachian Region:
  - buffering capacity
  - thiosalts
  - contaminants of concern
  - types of receiving environments
  - naturally occurring levels of metals
  - trends in benthic communities
  - acid generation and its effects
  - gold mines and iron ore mines
  - scope of the MMLER
- three case studies were selected for more detailed evaluation
  - Heath Steele Mines (I. Novaczek, W. Fairchild, and M. Patterson)
  - East Kemptville Tin Mine (M. Nickerson, R. Schwenger, and R. Parker)
  - Hope Brook Gold Mine (A. Mudroch, P. Davenport, and S. Ray)
- for many sites there was very limited information available
  - information was often limited to water chemistry data that had been collected by the mining company or by a government regulatory agency
  - few mining operations were required to conduct environmental effects monitoring programs as a requirement of their provincial operating permits
- aquatic effects monitoring was often conducted on an ad hoc basis in response to a particular environmental concern or event.

1.4.5 Preparation of the Working Group 6 Report

Review of Reports in AQUAMIN Database

- 94 documents or document sections for review were assessed and evaluated by individual members of WG 6 on the basis of individual areas of expertise:

Water Chemistry	Chris Mills
Sediment Chemistry	John Kwong
Toxicity	Benoit Godin
Benthos	Trefor Reynoldson (subsequently J. Hill and R. Hallam)
Zooplankton/Phytoplankton	Dave Sutherland
Macrophytes	Mark Thorpe
Fish	Wayne Knapp

  - reviewers focussed on extent and magnitude of effects, and the methods used for sampling

  - professional judgement was used to assign reliability and usefulness criteria to the reported data
- reviewers found inaccuracies in the criteria and sub-criteria ratings recorded in the AQUAMIN database and it was agreed that these ratings would not be referred to or recorded in the WG 6 reviews
- it was decided by WG 6, and agreed by the Steering Group, that the inclusion of minesites using unconfined tailings disposal (e.g., Island Copper, AMAX/Kitsault, Britannia Copper) in the review process was beyond the scope and terms of reference of WG 6
- details regarding the WG 6 review of documents are summarized in Appendix 2.

Methodology for Case Studies

- 5 sites were selected as case study sites:
  - Brenda Mines at Peachland, B.C. (5 reports)(Dave Sutherland and Elaine Koren)
  - Bell Copper near Babine Lake, B.C. (4 reports)(Wayne Knapp and John Kwong)
  - Myra Falls on Vancouver, Island, B.C. (21 reports)(Jenifer Hill and Judy Parkman)
  - Sa Dena Hes in Yukon Territory (6 reports)(Benoit Godin and John Kwong)
  - a "modified" case study was completed for the Snip Mine in B.C. (1 report) (Jenifer Hill)
- WG 6 also considerd Equity Silver, near Houston, B.C., as a potential case study site, but:
  - reports available gave a very limited view of the aquatic effects of mining at the site
  - operating mining company supplied little relevant information to AQUAMIN
  - therefore, any study would have been limited, and possibly biased, by its information base, and would have lacked the comprehensive overview of the other case studies
- drafts of all case studies were also submitted to the respective mine operating companies for review and comment

1.5 Background: *Metal Mining Liquid Effluent Regulations* and Guidelines

1.5.1 *Metal Mining Liquid Effluent Regulations*

The objective of the MMLER was to limit the discharge of deleterious substances from new, expanded, and reopened (since 1977) base metal, uranium, and iron ore mines. The regulations are permissive in that they set authorized concentration limits for deleterious substances in effluents discharged into waters frequented by fish. Concentration limits are presented in Table 1. The concentration limits are "technology based," with the best practicable technology (BPT) being achieved through recognition and utilization of the

constant physical and chemical properties of the metals arsenic, copper, lead, nickel, zinc, and radium-226.

For the purposes of the regulations, effluent includes mine water effluent, mill process effluent, effluent from tailings, treatment pond effluent or treatment facility effluent, as well as seepage and surface drainage from the site. Operators are required to measure or estimate the volume of effluent discharged.

Accompanying the MMLER is the Environmental Code of Practice for Mines, which is not legally enforceable. The intent of the code is to guide professionals in meeting their environmental control responsibilities. It also emphasizes pollution control practices that should be considered at all stages of mine–mill development, from initial planning through to abandonment.

Table 1: Authorized concentration limits of deleterious substances prescribed in the MMLER.

A: Authorized concentration limits of substances.

Substance	Maximum Monthly Arithmetic Mean (mg/L)	Maximum in a Composite Sample (mg/L)	Maximum in a Grab Sample (mg/L)
Arsenic	0.5	0.75	1.0
Copper	0.3	0.45	0.6
Lead	0.2	0.3	0.4
Nickel	0.5	0.75	1.0
Zinc	0.5	0.75	1.0
Total suspended matter (TSM)	25.0	37.5	50.0
Radium-226 (pCi/L)	10.0	20.0	30.0

Note: Concentrations are given as total values with the exception of radium-226, which is a dissolved value after filtration of the sample through a 3 micron filter.

B: Authorized pH levels.

Minimum Monthly Arithmetic Mean	Minimum in a Composite Sample	Minimum in a Grab Sample
6.0	5.5	5.0

1.5.2 MMLER and Gold Mines

The regulations do not apply to gold mines, which are defined as mines where the gold produced is recovered at the site by cyanidation and accounts for more than 50% of the value of the mine's output. In the mid-1970s, there were few treatment methods in general use for controlling cyanide-bearing liquid and solid wastes from gold mines. Untreated cyanide-bearing gold mine effluents are generally very toxic to fish.[1] In 1977, Environment Canada decided to exempt gold mines using cyanidation from the MMLER. However, a gold mining working group was set up as part of a task force to encourage and promote the development of technologies to control cyanide concentrations in effluent. During the 1980s, Canada became a world leader in developing and implementing several technologies related to the control of cyanide, including alkaline chlorination, the Inco SO_2/air oxidation process, hydrogen peroxide oxidation, cyanide regeneration, and optimization of natural degradation in tailings impoundments. Commercially proven cyanide treatment technologies are now in place at all gold mines in Canada.

1.5.3 Metal Mining Liquid Effluent Guidelines

The Guidelines for the Control of Liquid Effluents from Existing Mines, hereafter referred to as MMLEG, were published at the same time as the MMLER to establish effluent quality objectives for existing metal mines, other than gold mines using cyanide, that commenced operation before February 25, 1977. Acceptable levels for substances in the guidelines are the same as authorized levels for substances prescribed in the MMLER (Table 1).

Effluent quality objectives are not legally enforceable for these mines, but their operations are subject to the general provisions of the *Fisheries Act*. Compliance with the guidelines is considered to meet the spirit of the law, but discharging an effluent that is acutely lethal to

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[1] T.W. Higgs Associates Ltd. 1992. Technical Guide for the Environmental Management of Cyanide in Mining. Prepared for the Cyanide Subcommittee of the British Columbia Technical and Research Committee on Reclamation.

fish may be an offence under Subsection 36(3)[2] of the *Fisheries Act*. A mine may be legally obligated to meet the guidelines if a federal, territorial, or provincial government agency imposes these limits in a regulation, permit, or licence issued under its legislation.

1.5.4 Guidelines for the Measurement of Acute Lethality

The MMLER do not require acute lethality testing, and do not require that effluents be non-acutely lethal, but Environment Canada developed Guidelines for the Measurement of Acute Lethality in Liquid Effluents from Metal Mines, which accompany the MMLER. These guidelines specify a bioassay test procedure in which fish (rainbow trout) are exposed to undiluted effluent for 96 hours. If 50% of the fish survive, the effluent is considered to have passed the test. As stated above, mines are subject to the general provisions of the *Fisheries Act,* but discharging acutely lethal substances into waters frequented by fish may be considered a violation under the act.[3]

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[2] Subsection 36(3): "no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water."

[3] The current Environment Canada reference method for toxicity testing using rainbow trout is presented in: Environment Canada. 1990. Reference Method for Determining Acute Lethality of Effluents to Rainbow Trout. Conservation and Protection, Ottawa, Ontario. Report EPS 1/RM/13.

2 Appalachian Region

2.1 Case Study Sites

2.1.1 Heath Steele Mines

The Heath Steele Mine is located in Northern New Brunswick and has been the site of mining activity for zinc, copper, and lead since 1955. Mineral ore has been recovered through open pit and underground mining methods. The mine is currently operating and processes some 2700 tonnes of ore per day. Because of its status as an existing mine, the Metal Mining Liquid Effluent Regulations do not apply to this operation.

This mine has had a varied record of compliance with the requirements of its provincial permit which specifies adherence to the Metal Mining Liquid Effluent Guidelines. In recent years, the final effluent from the tailings pond has usually been in compliance with the MMLEG with only a few excursions each year. Acid mine drainage seeps from waste rock piles and site infrastructure and enters local water courses. This has resulted in some extensive aquatic effects downstream of the mine.

Documented aquatic effects in the receiving waters of this mine include elevated concentrations of zinc and lead in water, elevated concentrations of copper, lead and zinc in stream sediments, reduced fish populations and reduced density and diversity of benthic invertebrates. It should be noted that a reduction of these effects has been noted over the past few years.

For the most part, the monitoring program at Heath Steele has been adequate to detect impacts and changes. The water quality monitoring program has been continuous for many years and the benthic community monitoring has been repeated at regular intervals over the past two decades. The fish population surveys have been more intermittent. The review of the information raised some questions about the adequacy of some of the control stations.

2.1.2 East Kemptville Tin Mine

This open pit mine, located in south-west Nova Scotia, operated from 1985 to 1992 and was subject to the Metal Mining Liquid Effluent Regulations. Except for a period of 4 months just after start up, it maintained a good record of compliance with those regulations. Surface and ground water quality monitoring at the site was extensive during the operation and that program is continuing, in a somewhat reduced form, while the mine undergoes reclamation.

Biological monitoring at this site was very sporadic and included a few intermittent surveys of benthic invertebrates, fish populations, and bioaccumulation. Impacts from this operation were limited to the immediate receiving stream and were associated with habitat damage caused by siltation during the construction phase of the mine. The effluent contained significant concentrations of fluoride and one study demonstrated that fish in the receiving waters were accumulating fluoride in their bones. No pathological effects of this bioaccumulation were detected.

Surface water quality objectives were established for this mine and a multi-stakeholder monitoring committee was created to review the water quality results. This process, with the full participation of the mining company, has proven to be an effective mechanism to evaluate changes and trends in receiving water quality as a result of the mine operation. The mine has an excellent record of operating in such a manner that the water quality objectives have been consistently met since production began.

2.1.3 Hope Brook Gold Mine

The Hope Brook Gold Mine, located in south-west Newfoundland, began operation in 1987. Initially, gold was produced by heap leaching ore extracted from an open pit. Since 1989, ore has been produced from an underground mine and gold has been recovered by gravity separation, cyanide extraction and carbon in pulp technologies. Due to economic and environmental problems, operations ceased from May 1991 until July 1992 when the current operator, Royal Oak Mines Inc., took over the operation. Since this gold mine uses cyanidation to recover the majority of the gold, it is not subject to the Metal Mining Liquid Effluent Regulations.

Environmental monitoring has consisted of measurements for metals, cyanide, and ammonia in water, sediment, and biota samples. One study examined the benthic community in streams near the mine. The monitoring detected elevated concentrations of copper and cyanide in the receiving waters during the early years of the operation but that situation has improved in the past few years. There has been a pattern of increasing concentrations of metals in sediment samples from both the freshwater and salt water stations downstream of the mine.

In 1987 and 1989, metals were measured on samples of brook trout collected downstream of the mine and no increase in metals were determined. Efforts to repeat this study in 1989 and 1990 failed because no fish could be captured. This effect was attributed to degraded water quality in the freshwater receiving environment. Lobsters and mussels collected in the marine environment downstream from the mine have demonstrated increased concentrations of metals in tissue samples but the data were quite variable from year to year. There were no significant changes in the benthic community in the freshwater stream sampled between 1985

and 1989.

The water quality monitoring appears to be adequate to assess changes over time and to identify the magnitude and extent of those changes. There have been problems with sample collection and analyses over the years, particularly for the sediment and biota samples (see case study for details). This monitoring program would benefit from the implementation of thorough QA/QC practices.

2.2 Non-case Study Sites

2.2.1 Brunswick # 6

Over 12 million tonnes of copper, zinc, lead, and silver ore were produced from this open pit mine between 1966 and 1983. As an existing mine, the MMLER did not apply to this operation. The mine area is currently undergoing reclamation. Two brooks, which flow through the site and to the Nepisiguit River, were adversely impacted by mine water discharges and acid mine drainage from on-site waste rock piles. In the 1970s and 1980s, Knight's Brook supported only a very limited aquatic community and no resident fish population. In 1993, a survey indicated that Atlantic salmon were spawning to a limited degree in the lower section of Knight's Brook. For a number of years, the Nepisiguit River was negatively impacted by the drainage from the mine. Since 1985, successful salmon spawning has occurred downstream of the mine.

2.2.2 Brunswick # 12

In operation since 1964, this underground mine produces 10,000 tonnes per day of ore containing zinc, copper, lead, and silver. This mine is not subject to the MMLER but does operate under a provincial Certificate of Approval which specifies that the mine should adhere to the MMLEG. This mine has traditionally been out of compliance for zinc in its final effluent. Thiosalts, partially oxidized sulphides, also cause degraded water quality downstream of the mine. The thiosalts continue to oxidize to sulphate in the river downstream of the mine and this leads to a significant drop in the pH of the river water. As a result, significant impairment to the benthic community and a loss of all fish has occurred in the freshwater environment for 35 kilometres downstream from the mine. Although sediments in Bathurst Harbour showed elevated metal levels, marine bivalves in the same area did not show any indication of accumulating these metals.

A new water treatment plant was commissioned in 1993 and has brought the effluent into compliance with the MMLEG and is expected to result in some reduction in thiosalt

discharges.

2.2.3 East West Caribou Mines

Located in north-eastern New Brunswick, this open pit and underground mine produced lead/zinc concentrates for a few years in the 1970's and again in the late 1980's. Contaminated runoff and seepage from waste rock areas and tailings ponds have caused degraded water quality downstream of the mine. During the last operating period (1987-1989), the MMLER applied to this site.

Concentrations of zinc in the receiving stream 4 kilometres downstream of the mine are elevated more than 300 times the upstream water quality. At the mouth of the brook, some 35 kilometres downstream of the mine, zinc concentrations are more than 40 times background and exceed Canadian Water Quality Guidelines for the protection of aquatic life by an order of magnitude.

No information on any impacts to fish or benthos was found for this site.

2.2.4 Brunswick Mining & Smelting Lead Smelter

This operation was included in the review because it serves as an example of the impacts of a cadmium discharge to the marine environment. This area has also been the subject of a considerable amount of monitoring activity since the plant began operating in 1966. From 1966 until 1980, the smelter discharged untreated process water to Belledune Harbour. This resulted in the well-documented contamination of lobsters by cadmium. In 1980, a waste water treatment plant was commissioned at the smelter.

Surveys conducted from 1972 to 1981 indicated that the benthic community in the inner harbour was severely stressed. A 1988 survey indicated that the benthic community was recovering. Concentrations of metals in marine sediments are elevated above background for a distance of 16 kilometres south-east of the plant. No impacts were detected on zooplankton or fish populations. Mussels and lobsters have both shown elevated levels of cadmium and lead. The lobster fishery in the harbour was closed for a number of years as a result of this contamination. In 1993, cadmium levels in lobster were below the Canadian Food and Drug Directorate Guidelines and the restrictions on lobster fishing have been reduced.

2.2.5 Newfoundland Zinc

This mine, located in western Newfoundland, operated from 1975 until 1989, and produced nearly 7 million tonnes of zinc ore from both open pit and underground mines. As an existing mine prior to 1977, this mine was not subject to the MMLER. Because of the low levels of pyrite in the ore and the buffering capacity of the carbonate host rock, acid mine drainage and resulting metal contamination were never a problem at this site. The effluent from the mine was always in compliance with the MMLEG. No record of any biological monitoring was found for this site.

2.2.6 Buchans Mine

This open pit and underground mine in central Newfoundland operated from 1928 to 1984 producing zinc, lead, copper, silver, and gold. The MMLER did not apply to this site. Until 1966, tailings were deposited directly into Buchans Brook and Red Indian Lake. Since 1966, tailings were contained within a series of on-site tailings ponds. During its operation and since its closure, this mine has discharged effluents which exceed the limits of the MMLEG. Four of the five discharges are normally acutely lethal to fish.

Elevated levels of zinc have been reported in the Exploits River, over 60 kilometres downstream from the mine. Bottom sediments in Red Indian Lake show elevated concentration of lead, zinc, copper, and arsenic for up to 40 kilometres from the mine. No effects on fish or benthos from the mine were detected.

2.2.7 Rambler Mine

Located in north central Newfoundland, this mine operated a series of open pit and underground mines between 1964 and 1982. Because it was an existing mine, the MMLER did not apply to this operation. The waste rock and tailings are acid generating.

Water quality surveys conducted in 1991 and 1993 indicate increases in zinc, copper, lead, arsenic, sulphate, and hardness downstream of the mine. Also, stream sediments show higher concentrations downstream of the mine. No biological monitoring results were found for this site.

2.2.8 Iron Ore Company of Canada

This open pit magnetite mine, located in western Labrador, has been in operation since 1962 and produces about 22 million tonnes of iron ore pellets annually. A unique feature of this operation is that the process tailings are deposited directly into Wabush Lake. To date, some 520 million tonnes of tailings have been discharged to the lake and, in 1992, the tailings covered some 450 hectares of the lake. Very little monitoring has occurred at this site but water and sediment chemistry data indicate that iron and manganese migrate from Wabush Lake into lakes and rivers further downstream.

2.2.9 Gays River Mine

This underground lead/zinc mine operated from 1978 until 1982, and from 1990 to 1991. Gold ore from satellite mines was processed (non-cyanidation techniques) in the mill for a period from 1987 to 1989. The mine was subject to the MMLER and had an excellent compliance record with those requirements. The ore was found in a carbonate host rock and acid mine drainage was never a problem at this site. Very little environmental effects monitoring took place at this mine.

2.2.10 Yava Mine

This underground lead mine in Cape Breton operated from 1979 until 1981. Processing of the ore was conducted at a concentrator situated 13 kilometres away, so only mine water was discharged from the property to the Salmon River. The mine was subject to the Metal Mining Liquid Effluent Regulations and there were frequent excursions from those requirements, particularly for lead and total suspended material.

Localized, measurable effects on water quality, sediment quality, and the benthic community were identified in the studies conducted in the receiving environment of this Yava mine. These effects were restricted to an area extending from 20 metres to 100 metres from the discharge location. Sediments collected from a still water section of the river 1.2 kilometres downstream from the mine had elevated lead levels.

2.2.11 Nova Scotia Gold Mines

Gold mining in Nova Scotia dates back to the 1860's. Small mines have operated intermittently throughout eastern Nova Scotia since that time. Historically, mercury amalgamation was the extraction technique employed by these operations and mercury contamination is a concern. The gold was often found in close association with arseno-pyrite and the leaching of arsenic from tailings areas has been a concern as well. Tailings were traditionally disposed of in the nearest watercourse or bog. In more recent times, cyanidation and gravity separation techniques have been employed to recover gold. There was a small gold mining boom in Nova Scotia in the late 1980's. All gold recovery employed gravity separation techniques and all of the operations were subject to the MMLER. Compliance with those requirements was very good.

There have been very few studies conducted around abandoned gold mines but a thorough evaluation was conducted by government scientists in the area east and north of Halifax, and several excellent reports were published. These studies demonstrated arsenic and, to a lesser extent mercury, were released from these sites and caused contamination of water and sediments downstream. Some evidence of mercury and arsenic accumulation in fish and invertebrates was documented.

2.3 Regional Issues

During the course of reviewing the available aquatic effects information, several issues were identified which the Working Group members felt should be highlighted. Although some of these issues are regional in nature, there are national aspects to most of these items as well.

Buffering Capacity: Some of the freshwater and, of course, the coastal waters, are well--buffered and not as prone to impacts from metals. In many parts of the Appalachian region, however, the freshwater is very soft and poorly buffered and, as a consequence, much more sensitive to damage from metal contamination. In a similar vein, many of the region's ore bodies are sulphide-based and prone to AMD generation. Several lead/zinc operations (e.g., Daniel's Harbour, Gay's River), however, mined carbonate-hosted ores and AMD and metal contamination from these sites was never a problem.

Thiosalts: During the milling of sulphide ores, some of the sulphur is oxidised by oxygen dissolved in the processing streams. The kinetic restrictions of the oxidation process result in the formation of partially oxidised sulphur oxyanions ($S_2O_3^{2-}$, $S_3O_6^{2-}$ & $S_4O_6^{2-}$) that are collectively known as thiosalts. The presence of thiosalts in milling effluents can create serious environmental concerns in the receiving aquatic environment. Thiosalts pass through conventional lime neutralisation plants relatively unaffected and enter the receiving stream

where they are oxidised in the presence of bacteria to sulphuric acid. The acid can decrease the pH of the receiving water to a point where fish will avoid the stream. Thiosalts occur at three of the larger base metal mines in the Appalachian Region: Brunswick # 12, East West Caribou, and Heath Steele.

Contaminants of Concern: During the review of aquatic effects conducted by Working Group 3, several contaminants were identified which were of concern from an environmental perspective.

Zinc: A very common trend throughout the information reviewed was the presence of zinc in mine effluent. In fact, much of the reported non-compliance with the MMLER was due to the zinc limits being exceeded. Zinc is common and abundant in base metal ores but another important factor is the fact that it is quite soluble. This solubility also makes it more challenging to consistently reduce zinc concentrations below regulated levels. Zinc is toxic to aquatic organisms and it can also bioaccumulate in the tissue of aquatic organisms.

Cyanide: Solutions of cyanide salts are commonly used to extract gold from ore. As well, cyanide is a typical additive in base metal flotation processes. Although cyanide is not persistent and does not bioaccumulate, it can be very toxic to aquatic organisms.

Fluoride: Fluoride was detected in the effluent from the East Kemptville Tin Mine, the Mount Pleasant Mine and the St. Lawrence Mine in Newfoundland. While the acute toxicity of fluoride is not a serious concern, fluoride has been demonstrated to accumulate in the skeletal tissue of freshwater fish. The unregulated discharge of fluoride to the aquatic environment is a concern.

Aluminum: Aluminum is among the most common constituents of geological material. It can dissolve in water as a result of the processing of mineral ores or through natural processes, depending on factors such as particle size and pH. Aluminum is quite soluble in water and has been demonstrated to be acutely toxic to aquatic organisms. The concentration of aluminum in mine effluents is not controlled by the present MMLER. The adjustment of pH to precipitate the regulated metals (zinc, lead, copper, etc.) does not necessarily remove aluminum.

Types of Receiving Environments: Beyond the issue of receiving water hardness as discussed above, are there types of receiving environments that are more susceptible to damage from mines? Are freshwater environments more sensitive than marine waters? Are lakes or slow flowing rivers more sensitive than fast flowing streams? Are there sensitive species in certain environments that need a greater level of protection than that provided by the MMLER? Do the MMLER depend on dilution and dispersion of mine effluents to ensure protection of aquatic life? There should be provisions in any amendments to the MMLER to deal with these

kinds of questions on a site specific basis.

Environmental protection strategies should not be restricted to end-of-pipe controls but should also include pollution prevention options, receiving water quality objectives and environmental effects monitoring to ensure that control measures are effective.

Naturally Occurring Levels of Metals: Because mines are developed in highly mineralized areas, the background levels for metals in fish tissues, in water, and in sediments are often difficult to define, particularly for areas that have already undergone significant development. How does one establish water quality objectives or sediment quality objectives when background concentrations already exceed common published guidelines? There are mechanisms for dealing with these types of situations but they must be used to be effective. A discussion of this issue related to the uptake of metals by marine bivalves is provided in Appendix 3.

Trends in Benthic Communities: Many factors can affect the natural variability in benthic invertebrate populations such as season, temperature, nutrients, substrate type, elevation, stream order, etc. These sources of natural variability often make it difficult to differentiate between natural changes and anthropogenic effects. Is there a relationship between statistical decision points and ecological significance? Are there ways to interpret this type of data with confidence? These may be questions to defer to Aquatic Effects Technology Evaluation (AETE).

Acid Generation and its Effects: Many of the problems associated with the release of metals, particularly contaminated seepage from waste rock and tailings areas, are related to the whole issue of AMD. Do the MMLER deal adequately with this question? After the extensive research by the BCAMD Task Force and MEND, where are we going with this issue? Should the MMLER be amended to reflect new thinking (e.g., underwater disposal)?

Gold Mines: The present MMLER do not apply to gold mines. What are the environmental concerns and impacts from gold mines? Should gold mines be included under MMLER, and, if so, for some parameters or for all parameters? If the effects are different from metal mines, would a separate regulation for gold mines be a better strategy?

Iron Ore Mines: There are two open pit iron ore mines in Labrador which practice unconfined disposal of tailings into lakes. These mines are not subject to the MMLER because they were in operation before 1977. The current regulations do not allow for the unconfined disposal of tailings. Has this practice caused environmental damage? The sites in Labrador have not been studied to any great extent. Should the regulations be amended to allow this practice? Should these operations come under site-specific regulations?

Scope of the MMLER: The *Metal Mining Liquid Effluent Regulations* did not apply to any mining operations in the Appalachian region when this review was conducted. However, some mines were subject to the regulations when they were in operation. This often meant that there were different environment standards and expectations from mine to mine and province to province. This issue of regulated and guideline mines should be resolved. How can the amended regulations be made compatible with provincial requirements? Should other types of mines be included? Is there a need to include other contaminants in an amended MMLER (e.g., Al, CN, other metals, ammonia-nitrogen)? Should toxicity testing and/or EEM studies be mandatory for all mines? How can the regulations be made more flexible to deal with site specific considerations?

2.4 Conclusions and Recommendations

1. For the most part, information on aquatic environmental effects monitoring was lacking for many of the mining operations in the region. Only a few operations had any kind of regular monitoring programs which examined effects on water, sediment, and biota. Generally, aquatic environmental effects monitoring has not been required by either federal or provincial regulatory agencies. The lack of consistent environmental effects monitoring makes the evaluation of potential impacts and a comparison between sites difficult.

   Recommendation: All mines should conduct regular monitoring of their receiving environment and a consistent, standardised approach to environmental effects monitoring should be utilised.

2. The types of aquatic effects determined by this review ranged from no detectable impacts up to significant impacts measured tens of kilometres downstream.

3. There was close correlation between acid mine drainage and degree of impact. Often, the documented impacts were caused by acid seepage from waste rock and tailings disposal areas rather than the mine and process water (e.g. Heath Steele Mines, Buchans, Brunswick #6).

   Recommendation: Environmental protection strategies must include acid mine drainage from non-point sources.

4. Continuing negative impacts from closed and abandoned operations were identified at several sites (e.g. Brunswick #6, Buchans, Rambler, East West Caribou).

Recommendation: Environmental protection strategies must include closed and abandoned mines; environmental impacts and concerns do not end when production ceases.

5. There were several base metal and gold mines where no measured aquatic effects had resulted. These were gold mines not using cyanide or mines not experiencing acid mine drainage problems or mines located on highly buffered receiving waters which were resistant to impacts. This conclusion should be qualified by stating that environmental effects monitoring at most of these sites was very limited (e.g. Gays River, Daniels Harbour).

   Recommendation: The MMLER appear to be effective at protecting the environment in some cases; particularly when acid mine drainage is not a problem at the site.

6. The current *Metal Mining Liquid Effluent Regulations* did not apply to the majority of the sites reviewed by this working group.

   Recommendation: The *Metal Mining Liquid Effluent Regulations* should be amended so that they can be applied uniformly to all mining operations.

7. Although it was common to monitor the presence and concentration of metals in sediments, there was limited understanding about the potential biological effects of this type of contamination.

   Recommendation: Further research is required in the area of understanding and assessing potential impacts from contaminated sediments. Hopefully, some of the work initiated by the Aquatic Effects Technology Evaluation (AETE) will address this issue.

8. Biological tissues are more effective as indicators of effects if they are sampled in a scientifically rational manner and the data are used with all of the limitations in mind.

   Recommendation: In order to properly compare the results of heavy metal determinations in tissue, uniform size and age of samples are required; strict QA/QC must be followed; and only dry weight determinations should be used.

3 Eastern Canadian Shield - Quebec

Foreword

This document presents the main conclusions from the work performed by the Quebec sub-group. The synthesis includes a first component on the effects on the aquatic environment taken from the three case studies selected for Quebec. A second component gives the comments and reflections of the members on the federal regulations and the approaches recommended. This text reflects the opinion of the majority of the sub-group members. Appendix 4, prepared by Mr. Alan Penn (Cree Regional Authority) offers certain clarifications and comments on the regional synthesis. Similarly, it should be mentioned that Mr. Yves Thomassin considers that all the recommendations concerning the control of water from inactive sites are irrelevant, arguing that the regulations for abandoned sites should be made separately from those for active sites.

3.1 Introduction

The selection of case studies was made from the AQUAMIN database. A summary of the available data was prepared first (Regional compilation report, Sub-group 4-Quebec, November 1994). This summary revealed how little information was available on effects in aquatic environments and the limitations inherent on the choice of case studies for Quebec. The three case studies were selected because of the greater amount of information on biological effects (and not on the basis of representativeness, ore type or sensitivity of the receiving environment).

3.2 Effects on the Aquatic Environment

3.2.1 Mine Sites in Operation

3.2.1.1 Mines Gaspé

Mines Gaspé is located on the Gaspé Peninsula at the head of the York River. The mine site contains a copper mine, a concentrator and a refinery. The quality and quantity of information available helped a great deal in reviewing the Mines Gaspé case study, and consequently enabled the group to reach the conclusions below.

Probably because of the pronounced hardness of the water in the final effluent and in the receiving environment, no toxicity was observed, except for a brief period in 1982 following an accidental acid spill.

Copper accumulation in the sediments is apparent only at station Y-22, located 350 m downstream from the final effluent discharge point.

Higher metal concentrations were observed at the surface of a core sample taken more than 100 km downstream from the mine site. However, interpretation of these preliminary results from a single core sample is difficult because the real rate of sediment accumulation or the transport process of contaminated sediments in the river are not known.

The evaluations indicate that the benthic communities in the York River are affected by the mining operations. During the period from 1977 to 1981, the number of taxons and density of organisms declined as far as 16 km downstream on the York River. The impact of the mining operations on these communities was obviously stronger at the stations located near the mine site. In 1982, an accidental acid spill had a pronounced effect on the benthic communities over a distance of 48 km. The impact was observed downstream until 1984. Since 1989, the situation has been stable at the two stations near the site (< 1 km). These stations are characterized by the presence of species which are tolerant to metals (*Cricotopus* spp.) and the absence of sensitive species (*Tanytarsus*spp.). The presence of Ephemeroptera near the point of discharge from the mine into the river suggests an improvement in water quality.

The populations of juvenile salmon were also affected by the acid spill of 1982. Since 1987, the number of juvenile salmon has been stable and relatively high, the production of young salmon is comparable to that of the other rivers of the Gaspé Peninsula and the number of spawners remains high.

Preliminary data show that the zooplankton found at the outlet from the mine site contain higher copper concentrations than those observed at the other sites sampled. The livers of fish consuming them are also characterized by high copper levels. However, according to the authors of the study, no impact in terms of survival or growth of the salmon has been observed.

3.2.1.2 Lac Matagami

The mine site includes many base metals mines and presently one copper-zinc concentrator. The Lac Matagami mining complex is located in the James Bay region 180 km north of Amos. The results described below are based on a study done as part of a plan for closing the site.

Thus there is no temporal analysis of the effects on the aquatic environment. The study was well planned and the data collected allow, to a certain extent, a good characterization of the aquatic ecosystems concerned and the impacts of the mining activities on them. However, there are some problems with the choice of sites representing undisturbed environments for the analysis of benthic communities.

The results of the water quality analyses indicate that the mine effluents contribute some loading of heavy metals (mainly zinc) and that dilution is rather low. A comparison with the background stations and Hydro-Québec data collected in 1991 shows that the impacts of the mining activities on water quality, in the case of Lalanne Creek at least, extend over a distance of 15 km. However, it should be noted, given certain discrepancies between the two laboratories used for quality control, that these data should not be accepted without reservation.

The sediment analysis shows that the mining activities have an impact in terms of contaminating the beds of watercourses over a distance of several kilometres downstream from the discharge sites. The data demonstrate that there are high accumulations of zinc (up to 6,000 mg/kg) and, to a lesser extent, of copper in the sediments near the mine sites.

The analysis of benthic communities at the background stations reveals that these points are not all representative of non-degraded stations, which limits the interpretation of the results. In general, the benthic communities in Lalanne and Veract Creeks and the Allard River are affected by the discharges from the mine site.

The study of fish communities does not reveal any appreciable differences between the communities at the stations near the mine sites and those at the background stations (abundance of species). The mining activities do not seem to affect the fish communities in terms of flesh and liver contamination by metals.

Nevertheless, it should be mentioned that operation of the Lac Matagami mine has involved the loss of a lake, Watson Lake, which has been used as a tailings basin since 1963.

3.2.1.3 Other Study Documents

An evaluation was done of the information contained in the AQUAMIN database. Information on the situation prevailing between 1978 and 1980 and on the effects of mine operation on the aquatic environment in the Rouyn-Noranda region is provided in the reports

of the Bureau d'étude sur les substances toxiques (B.E.S.T.)[4].

Since the adoption in 1989 of the Directive 019 by the Ministère de l'environnment et de la faune du Québec, the main source of data related to the aquatic environment and mining operations comes from impact studies or monitoring studies conducted by the companies according to the directive. These characterizations focus more[5] on water quality and sediments chemistry, and provide limited information on the initial state of the aquatic environment and the benthic and fish fauna. Thus, there is little information available on the ecological impacts of mining operations.

Compilation of the data from these documents and a review of the conclusions indicate a general tendency toward increasing metal concentrations in the sediments and water downstream from mine sites.

3.2.2 Inactive Mine Sites

3.2.2.1 Aldermac

The Aldermac site, located in the Rouyn-Noranda region, is an inactive tailings area which has been abandoned for more than 50 years. This site was worked from 1932 to 1943 for copper, gold and silver, and is a typical case of acid mine drainage. The contamination in the receiving environment extends 17 km downstream from the tailings site. The data from characterization studies on the tailings site and the receiving environment conducted in 1974, 1983 and 1994 indicate that the water and sediments of Arnoux Creek, Arnoux Lake and Desserat Lake (Arnoux Bay) are contaminated by heavy metals (Cu, Fe, Zn, As, Cd, Pb, Ni and Al).

The acidification of the aquatic environment is evident as far as Arnoux Bay. An inventory done in 1990 shows that the fish communities are affected by this pollution: there is an absence of fish in Arnoux Lake, indicating a very severe deterioration in the condition of the aquatic communities.

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[4] "Office for the study of toxic substances" - Tr

[5] French "plus" missing and assumed from the context ("sont axées *plus* sur"). - Tr

3.2.2.2 Other Study Documents

Inactive gold mines were analysed and evaluated as of 1978 by the Bureau d'étude sur les substances toxiques (B.E.S.T.) for contamination of the sediments in lakes and watercourses by mercury content from amalgamation. Contamination of the aquatic environment was studied in the sectors of Val-d'Or, De Montigny Lake, Malartic Lake, Preissac Lake and Rouyn-Noranda.

The characterization studies and the programs to restore acid tailings sites, such as East Sullivan and Canadian Malartic in the north west part of Quebec, have underlined the major risk of aquatic environment contamination.

In general, there is little precise information available in Quebec on the nature of the effluents from inactive tailings disposal sites and their effects on the aquatic environment. Thus there is an urgent need for inventories and characterization studies.

3.3 Comments and Recommendations Concerning the Federal Regulations

3.3.1 Active Mine Sites

The effectiveness of the federal regulations in protecting the receiving environment cannot be demonstrated using the results of the documents examined. The link between the federal regulations and the results of the environmental studies related to mine operation cannot be made under the current regulations. The regulations in force are the product of technological reasoning, in that the standards were established on the basis of the performance of the technology which existed (that is, the best practicable technology) when they came into effect. While there may be situations in which no effects are detected for effluents which comply with these regulations, such situations are only circumstantial; this does not mean that compliance with the regulations necessarily ensure protection of the aquatic environment.

To make the link between the quality of mine wastes and maintenance of the sustainability of the aquatic environment, the federal government's approach to regulations must be changed. It should allow the establishment of objectives for wastes based, not on technological performance, but on the capacity of the aquatic environment to receive such wastes.

Accordingly, it must be realized that this kind of approach specifies the ultimate goal to be reached in terms of the water quality of such wastes for an operation. It is possible that the economically applicable technology will not perform well enough to meet such requirements. In such situations, the objective is still to achieve the concentrations and loadings justified to maintain a sustainable ecosystem, while operators must improve their processes and

treatment, as new technological developments become available, in order to meet environmental requirements.

This approach, based on the capacity of the aquatic environment to receive waste, is already defined in section IV.2 of the Environment Quality Act of Quebec and in the regulations on cleanup certification. It is embodied in the Programme de Réduction des Rejets Industriels[6] (PRRI) of the Ministère de l'environnment et de la faune du Québec. Implementation of this program does not yet apply to the mining sector, only to the pulp and paper sector.

3.3.2 Inactive Mine Sites

In Quebec, since adoption of the regulations implementing Bill 130 to amend the Mining Act, all operators of mine sites in a production phase on March 9, 1995 are required to submit a restoration plan to the Ministère des ressources naturelles and to comply with the standards on effluents in force under the Directive 019 of the Ministère de l'environnment et de la faune du Québec after ceasing production activities. The main objective is the rehabilitation to achieve a satisfactory condition of the mine site.

However, mine sites which are presently inactive are not included in Bill 130 mentioned above on site restoration. Moreover, one must remember that the federal regulations and Directive 019 are designed for operating mines and can not apply directly to inactive sites unless there is a water or tailings treatment system that is maintained. Yet various measures to limit contamination of the environment can be taken by the provincial authorities when necessary.

For the inactive sites, it would be important for the federal regulations to be applicable. Various scenarios or choices of approach to set the standards may be considered; the essential thing is that the scenario selected should take into account the protection of the aquatic environment. The following paragraphs are an example of an approach designed with the receiving environment in mind.

If we want the regulations to apply to the liquid wastes from an inactive site, using the receiving environment approach (as for active sites), a new section must be designed in the regulations which would define a procedure for determining the limits of wastes in terms of concentrations and loadings as a function of the criteria for the protection of the aquatic environment. This procedure must be based on an approach which assesses the capacity of the receiving environment to accept these effluents without being affected by them in the long

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[6] "Industrial waste reduction program" - Tr

term. The adoption of a preventive approach thus becomes very relevant indeed, if we consider that the receiving environments of such sites should be rehabilitated in a fairly short time.

The development of such a section of the regulations must not be based on technological performance principles, but on principles of long-term protection of the receiving environment. The approach advocated for active sites should be adopted.

3.4 Comments and Recommendations Concerning Aquatic Environment Monitoring Studies

In light of the analysis of data from the AQUAMIN document base in Quebec and the case studies, we must accord the utmost importance to the reliability of sampling and analysis measurements of the aquatic environment, including those of the water, sediments, fish, benthos and so on.

Each site is unique, but a reliable procedure must be used, one with a predefined capability, in order to make a valid interpretation which can be compared from one site to another.

For each of the sites studied, the effect of mining activity on the aquatic environment is observed. Depending on the site, the influence varies from very severe (Aldermac) to more limited (Mines Gaspé). Similarly, the area affected varies according to the characteristics of the receiving environment (buffering capacity, watercourse flow rate) and the characteristics of the waste (flow rate, concentration and so on).

The observations have been made via studies which differ widely from one site to another. This difference makes any direct comparison between sites very difficult, not counting the fact that certain studies do not identify the methods used, thus limiting the interpretation of results to qualitative considerations only.

The example which best illustrates the difficulty in interpreting the results is that of the sediments. When the portion of the sediments used is not identified, the concentration reported may be any value between the average for the total sample (including sediments which do not come from the mining operation) and the concentration which is representative of the mining activity (sediments from the surface layer only). Moreover, the particle-size fraction selected has just as great an influence on the analysis of the results.

When this information is not available, we should limit our deductions to a qualitative interpretation. Still, we can identify the existence of a change, although its intensity or extent cannot be measured.

The immediate lesson to be derived from this situation is that we must require a very clearly identified, uniform procedure for all future studies, whether in the context of EEM studies or any other studies to be done.

Continuing with the example of sediments, we will illustrate various aspects of a procedure to facilitate coordination among the results from different sites. The following elements should be included in the minimum amount of information provided:

- a description of the sampling plan and sampling sites; the hydrology and hydraulic (flow type, velocity), and a comparison of the site with other portions of the river;
- the sampling procedure, identification of the equipment used, the intended depth of the sample and the actual depth obtained;
- a description of the sample handling, such as screening, procedure to composite samples and consideration of the sediment deposition profiles.

To certain members of the Sub-group 4, the concept of EEM studies should only be useful once a strategy for the waste reduction is applied (that is to attain an optimum performance of the treatment system relative to protection of the receiving environment).

For future EEM studies, moreover, the approach should include a statistical plan to ensure that the information collected (water, sediment, fish and benthos) meets pre-established criteria on statistical power. Thus it is important for the study plan to comprise hypotheses which can be verified after sampling and analysis.

Each site is unique, but we must ensure that a reliable methodology is consistantly applied in order to make a valid interpretation which can be compared from one site to another.

3.5 Other Recommendations

The Environmental Code of Practice, published at the same time as the federal regulations of 1977, set out a number of basic principles for managing water and mine tailings to limit the contamination of surface and ground water. Several elements of the Code of Practice should be revised from a regulatory viewpoint and for the purpose of updating the information.

In our opinion, action for the purpose of evaluating water and tailings treatment systems and improving management practices to minimize the release of contaminants at the source is essential if we are to succeed in minimizing the effects of mining operations on the environment.

The quality of the aquatic environment could also be managed by a group formed of people from the community interested, the industrial firm (or firms) concerned, the government or governments, local pressure groups or other stakeholders. Such a group would be responsible for preparing recommendations concerning the objectives of treatment required to satisfy and protect the various uses of the water and concerning the measures to be taken to protect the environment in accordance with local priorities.

In that case, the formation of a management group should be included in the regulations. Its operation, objective and power would be well defined in the regulations and would be used to manage the water resource at the local level in all respects determined by legislation.

3.6 General Conclusions

The general findings of the documents from the study cases and all the bibliography consulted are that mining operations do affect the aquatic environment in Quebec.

We must conclude from the lack of information on the condition of aquatic life near mine sites that monitoring studies will be necessary for a better assessment of the environmental effects, whether this is done through regulations or otherwise.

A more dependable approach is necessary, one with objectives for protection of the aquatic environment. This simple, preventive approach already exists in Quebec and should be given precedence, especially since, to our knowledge, other provinces (Ontario and British Columbia) have adopted a similar approach.

4 Eastern Canadian Shield - Ontario

4.1 Summary of Environmental Effects

4.1.1 Water

- Effluent concentrations increased contaminant concentrations downstream. In the case of Red Lake mines, background water quality is achieved km downstream of the effluent discharge. At the Hemlo site Provincial Water Quality Objectives (PWQO) for ammonia, free cyanide, copper and nickel were exceeded 2.3 km downstream of the Lim Lake discharge. In the Frank Creek watershed antimony, copper, molybdenum, nickel, free cyanide and ammonia levels periodically exceed PWQO at the Frank Creek discharge, approximately 5.7 km downstream of the effluent discharge from the Molson Lake Tailings Basin to the Frank Lake system. The feeder stream at Kidd Creek that receives effluent from Kidd Creek and drains into the Porcupine River exceeded PWQO for Zinc Cd, Se, and Cu. At the Winston Lake Mine Zinc exceeds the PWQO where the effluent is discharged into the Whitesand River.

- In one case study (Winston Lake), an effect resulting from the lime treatment of the mine's final effluent was observed. The discharge of high levels of calcium into the receiving lake had led to development of a chemical density gradient that prevented lake turnover and mixing. This resulted in depletion of dissolved oxygen in the hypolimnion of the lake.

- Effluent quality from historical sites has been improving over time (Winston Lake, Red Lake).

- Physical changes may have impacted more than chemical changes. At the Red Lake camp the damming up of Balmer Lake may be more harmful to the fish population than present water quality.

4.1.2 Sediment

- Baseline information (prior to mine development) showed that metal concentrations in sediments in most of the Case Study areas naturally exceeded Provincial sediment quality guidelines (Hemlo, Winston Lake, Kidd Creek).

- At most sites there was an increase above baseline in metal concentrations. At the Hemlo camp increases in antimony, copper, manganese, molybdenum, nickel, tin and zinc were

noted in Lim Lake sediments. However, in the Frank Lake system sediment concentrations remained unaffected. At the Winston Lake Mine copper and zinc were generally found to be elevated (up to 8 km downstream) relative to levels found in sediments from the control station. At the Kidd Creek mine downstream stations showed elevated concentrations of Pb, Cd and Se.

- Historical tailings deposits, within the receiving waterbody, at some mine sites have affected chemical and physical sediment quality (Red Lake).

4.1.3 Benthic Organisms

- In areas where there had been historical mining operations, baseline benthic studies indicated that benthic communities were impacted by past mining activity, since only pollution tolerant species were present (Winston Lake, Red Lake).

- Some studies revealed that at sites immediately downstream of a mine discharge, there were lower species diversity and lower abundance of pollution sensitive benthic organisms found (Winston Lake), while in other studies benthos communities were impacted (Red Lake). Due to lack of sufficient habitat information for some sampling sites, no definite cause/effect relationship could be established (Kidd Creek, Hemlo).

- In areas where tailings had been deposited in receiving waters, benthic communities were impacted. However, benthic samples taken near emergent vegetation indicated that availability of suitable habitat was more of a restrictive factor than water or sediment quality in determining benthic community structure (Red Lake).

4.1.4 Fish

- Baseline studies indicate that elevated Hg levels in fish muscle are common in Northern Ontario lakes (Hemlo, Winston Lake).

- Post operative studies showed that metal concentrations in fish muscle did not increase after mine operation (Hemlo, Red Lake, Winston Lake).

- Reproductive impairment may be caused by physical disturbances in receiving waters. For example, reduced flow in Balmer Creek may be responsible for lack of any observed walleye spawning at the Red Lake mine sites.

- The Ontario MISA Status Report for the Metal Mining Sector (1990-1991) indicated that of the 17 metal mines in operation in the province at that time, 6 had discharges that were lethal to trout . Five of those sites had effluents that were also lethal to *Daphnia*. Of the 13 gold mines surveyed, 3 sites had effluents that were lethal to trout. The effluent from one of these two sites was also lethal to *Daphnia* and there was one site where the effluent was lethal to *Daphnia* but not to trout.

- In general, for the case study gold mines, non-lethal effluents were produced.

4.2 Summary of Causes of Effects

4.2.1 Water

- Most increased metal concentrations in receiving water courses were the result of effluent discharge and are directly related to the size of the receiver and its assimilative capacity (Hemlo, Red Lake). However, at other sites, activities(mining, waste water treatment plants, landfills) upstream of the site also contributed to the increased concentrations in the receiver (Kidd Creek, Winston Lake, Red Lake).

- Lime treatment in combination with the bathymetry of specific lakes could cause the formation of a chemocline.

- Ongoing abatement strategies have improved the effluent quality discharged from historical mine sites (Winston Lake, Red Lake).

4.2.2 Sediments

- In areas of high mineralization it is not unusual for background sediment metal concentrations to be elevated beyond Provincial quality guideline levels.

- Some increases above baseline concentrations in sediments were directly related to effluent discharge into the receiving waterbody. Other increases in sediment concentrations may be related to upstream activities (mining, waste water treatment plant, landfills, historical tailings) (Kidd Creek, Winston Lake, Red Lake).

4.2.3 Benthic Organisms

- Gross changes in benthic populations were easily identified (Winston Lake, Red Lake). At other sites where changes were more subtle it was difficult to establish cause/effect relationships due to a lack of detailed habitat information for sampling sites or a lack of resolution afforded by assessment of benthic organisms (Kidd Creek).

4.2.4 Fish

- Presence/absence surveys that were conducted at some of the case study sites make it difficult to determine cause/effect relationships. Adequate baseline, pre-operational data on fish populations and contaminant concentrations in the tissues are generally lacking.

- The Ontario MISA Status Report on The Metal Mining Sector (1990-1991) indicated that for the 6 sites where lethality to trout was noted, in all but one case (Geco, Manitouwadge), pH was high enough to cause acute lethality. Ammonia, zinc and nickel were other effluent constituents that may have contributed to the toxicity to trout.

- At 5 of the 6 sites mentioned above, effluents were also toxic to *Daphnia*. All except one of the five sites had high enough copper levels (>0.1 mg/L) to explain part of the observed toxicity. At all sites but Geco (Manitouwadge), pH levels above 10 were high enough to cause acute lethality on *Daphnia*. Ammonia and zinc were other constituents of these effluents that may have contributed to the toxicity.

4.3 Applicability/Effectiveness of the MMLER in Ontario

4.3.1 Jurisdiction

- Older mining sites typically have more severe problems than newer sites. Their construction and placement often makes remediation difficult and expensive (Winston Lake, Red Lake). Generally, these sites have fallen under the MMLEG. However, in Ontario, active abatement programs are implemented to bring older companies into compliance with new regulations from the Ontario Ministry of Environment and Energy (MOEE) and the Ontario Ministry of Natural Resources (MNR) not the MMLER/MMLEG.

- Currently in Ontario, new mine sites are required to submit a closure plan prior to development that establishes baseline/current conditions and proposed rehabilitation measures on closure. This requirement in combination with requisite monitoring required

as part of the Certificate of Approval (C of A) from the MOEE during the operation of the mine helps to determine impacts as the mine develops. Early detection of problems enables implementation of process changes or treatment that reduces impacts during operation and on closure.

- The MMLER do not address site specific conditions.

    1) In Ontario, the requirement of a non-lethal effluent removes some of the site specific variability introduced by receiver size and dilution capabilities.

    2) In Ontario, toxicity testing is required on a monthly basis. The MMLER only require toxicity testing every three months. Ontario's site specific C of A's allow for restrictions on contaminants that may be unique to one mine.

4.3.2 Parameters

- The case studies identified other contaminants of concern that are currently not regulated in the MMLER. These include: ammonia, calcium, molybdenum, and cyanide. However, these substances are included in the provincial Certificate of Approvals for some mines.

- Currently, there is no federal regulation for mine effluents to be non-toxic (Guidelines only). As a minimum, non-toxicity is considered necessary for basic protection of aquatic resources, particularly in areas immediately adjacent to the discharge(s). [Currently, MISA Regulations require monthly acute toxicity testing with the provision for chronic toxicity testing. Although standardized toxicity tests have been developed, their ability, in themselves, to identify the toxic components of the mine effluent is uncertain.]

4.4 Status of Monitoring Programs (Findings from Case Studies)

- Most biological monitoring studies conducted during the 1970s and 1980s are considered to be inadequate today to assess impacts on the aquatic ecosystems (*e.g.* lack of consistency in how monitoring was done, etc.). For example, chronic sub-lethal effects of contaminants discharged by mining operations on the health of resident fish were not evaluated.

- It should be noted that two of the four case studies were conducted on mine sites that were subject to the MMLEG only (Red Lake and Kidd Creek). Hence, the ability to evaluate the effectiveness of MMLER is limited. In addition, these mining operations were subject to a more stringent regulatory requirements from the province of Ontario.

- Government review, analysis and feedback on environmental monitoring programs were not always timely. Thus, problems were not always recognized as soon as they should be.

- Benthic and sediment surveys conducted, gave limited consideration to habitat variables such as water depth, flow rates, sediment particle size and nature, macrophyte cover, proximity to tributary outflow. The habitat strongly influences the benthic community present and it is essential to eliminate the habitat variability when attempting to establish the impacts of the mine discharge on the aquatic biota. Ideally, reference locations should possess habitat characteristics similar to those of the exposure locations. There were differences in substrate type and flow between exposure and reference areas that could have lead to some of the variation detected in the benthic communities. Due to habitat variability among sampling sites and insufficient numbers of replicates for thorough statistical analysis; no definite cause/effect relationships could be established from the data.

- Abandoned mining sites within receiving watersheds typically provide severe problems for newer sites in determining net effects from their operation. Their location and subsequent discharges often coincides with high contaminant levels in the watershed.

- For older mine sites as well as multi-use sites, it is difficult to separate historical impacts from present day (Red Lake) or distinguish net effects from only the mining operation itself. (Kidd Creek)

4.5 Recommendations to Improve Monitoring Programs

- Pre-operational baseline studies should include surveys of pollution sensitive species with sufficient sample sites and replicates to detect temporal and spatial changes.

- Monitoring programs/data must be supported with appropriate quality assurance/quality control (QA/QC) to reliably detect subtle changes in water quality prior to exceedance of receiving water quality objectives/criteria.

- For further studies, detailed habitat assessment should be conducted and comparable reference areas chosen. Studies should be done to determine the extent of the effluent zone and effluent concentrations at the sampling stations. Sufficient samples should be taken to allow use of appropriate statistics to determine spatial variation within and between sampling areas as well as temporal variations. If indices are used to determine community structure, a suite of different ones should be used, which include diversity, evenness, richness, dominance and similarity. Habitat preferences of different species

should be considered when establishing cause/effect linkages. Sediment quality studies should be included in future monitoring programs. AQUAMIN Report #187 study was well designed and further studies should follow this example.

- To evaluate the biological availability of contaminants to fish and large invertebrates (*e.g.* bivalves, crayfish) appropriate tissues (*e.g.* kidney, liver, hepatopancreas) must be analyzed. With the exception of mercury, muscle is not an appropriate tissue for use in biomonitoring.

4.6 Suggested Research Needs

- The following three-point approach for assessing the efficacy of effluent treatment procedures, and for evaluating chronic adverse effects (toxicity) produced by contaminants discharged in treating mining and milling effluents on organisms in receiving waters, is suggested to improve monitoring.

    1) Use information on contaminant concentrations in treated effluents, and on volumes of treated effluents discharged, to **calculate actual contaminant loadings to receiving waters**.

    2) Determine the **biological availability** of these contaminants by analyzing in a statistically appropriate number of fish species and benthic organisms per site.

    3) Evaluate whether these contaminants are producing chronic, adverse effects on the health of these organisms.

    4) Determine the significance of the chronic, adverse health effects on the viability of the overall receiving watershed ecosystem.

    5) Investigate the significance of measurable environmental effects (sediments, water chemistry, benthos and bioaccumulation) on the overall ecosystem health of the receiving watershed.

- Collection and availability of baseline data is not a requirement. This would probably be a requirement from the *Canadian Environmental Assessment Act* (CEAA) and any of the provincial statutes. The need to include such requirement under the MMLER versus harmonization with other legislation/jurisdictions should be considered.

- Chronic sub-lethal effects of contaminants discharged by mining operations on the health of resident fish were not frequently evaluated.

- Identification of suitable chemical tracers to confirm biota exposure, especially in multi-use sites.

- To verify whether there is a vacuum in environmental protection with or without presence of the MMLER (*e.g.* tabulate and compare the provincial environmental protection requirements of the mining sector).

- Effluent toxicity tests are a regulated requirement. A review of the use of standardized toxicity tests to determine real effects within the receiving environment is required.

5 Western Canadian Shield

5.1 Case Study Sites

5.1.1 Nanisivik Lead/Zinc Mine: Strathcona Sound, Baffin Island, NWT

The Nanisivik lead/zinc mine is located on northern Baffin Island, adjacent to Strathcona Sound, a narrow, deep fjord of over 50 km long, extending into the Borden Peninsula from Admiralty Inlet. The mine began production in October 1976, and is not subject to the MMLER. The ore consists of massive sulphide (pyrite) mineralization in a carbonate host rock. Ore is milled on site, and tailings are deposited in West Twin Lake, about 6.5 km from Strathcona Sound. The capacity of this lake has been exceeded, and tailings are now deposited subaerially in a portion of the lake. The tailings solids contain approximately 0.1 to 0.2% lead, 0.4 - 0.6% zinc and 0.01% cadmium. Treated effluent is discharged to Twin Lakes Creek, which flows through the mine site to the sound. Water quality monitoring has been conducted in Twin Lakes Creek, and water and sediment quality monitoring have been conducted in Strathcona Sound. In addition, benthic invertabrates, and macrophytes have been monitored in the sound. Limited monitoring of fish and seals has also been conducted.

Conclusions and Recommendations

- Twin Lakes Creek is a significant source of lead, zinc, and cadmium contamination in Strathcona Sound.
- Concentrations of lead, zinc and cadmium are elevated in the tissue of invertebrates and macrophytes living in Strathcona Sound, adjacent to the mine site. Limited assessments of the health of invertebrates indicate no impairment as a result of exposure to metals.
- Monitoring of fish and seals has been too limited to be able to reach any conclusions.
- Monitoring at Nanisivik would benefit from developing and focusing on specific questions related to aquatic resource protection.
- In light of concerns of residents of the nearby community of Arctic Bay about dust from the subaerially deposited tailings, it is recommended that effects of dust on organisms used as food sources be assessed. Results of this monitoring should be made available to the community in an accessible form.

- Methods to control dust should be included in a revised Code of Practice for mines

5.1.2 The Lupin Gold Mine: Contwoyto Lake, NWT

The Lupin Mine is located in the District of MacKenzie, NWT, on the northwest shore of Contwoyto Lake. The main ore zone consists of gold-bearing sulphides in beds and lenses of gneiss. The mill on site commenced operation in October 1982 using the cyanidation process. For a few weeks each summer treated effluent from the tailings management area is decanted into Seep Creek, a 6.5 km long creek which flows into Sun Bay of Contwoyto Lake. As the Lupin Mine uses the cyanidation process, it is not subject to the MMLER.

Conclusions and Recommendations

- Changes were detected in water borne metals levels in Outer Sun Bay, approximately 5.5 km from the mouth of Seep Creek. In 1985, metal concentrations in Seep Creek and Inner Sun Bay exceeded the Canadian Water Quality Guideline for the protection of freshwater aquatic life. However, the high water hardness may reduce the bioavailability of the metals.

- Due to the short seasonal effluent discharges exposure of biota to elevated metal concentrations is periodic.

- In general, biological effects of the Lupin Mine on receiving waters are limited to Seep Creek and Inner Sun Bay. Changes in numbers of snails, mites and oligochaete worms in Inner Sun Bay were observed after the first decant in 1985. However, the 1985 decant was unique since effluent was not treated to reduce arsenic concentrations. Reductions in numbers of snails may have been caused by sublethal effects of heavy metals or been a secondary response to reduced abundances of plant growth. Since 1985, effluent has been treated to reduce arsenic concentrations prior to discharge.

- No consistent, significant relationships or trends have been observed for the metal content of lake trout tissue sampled after the mine commenced operations.

- Monitoring at Lupin would benefit from developing and focusing on specific questions related to aquatic resource protection.

- Reference sites may not be adequate.

5.1.3 Cluff Lake Uranium Mine, Saskatchewan

The Cluff Lake Uranium Mine is located in northwestern Saskatchewan at 58°22'N by 190°31'W. The mine site area is characterized by rolling terrain, sand plains, dunes, moraines, sandy till and bedrock. The uranium deposits are situated in the Carswell Structure, a geologic anomaly between Carswell Lake and Cluff Lake. Four ore bodies in the Cluff Lake area have been mined since 1980.

Milling operations during Phase I, from 1980 to 1984, processed high and medium grade ores and produced three varieties of tailings:

- Gravimetric tailings which were stockpiled for future reprocessing for further uranium recovery.
- Leach tailings, containing gold and uranium, which were are stored in concrete vaults.
- Conventional uranium leach process tailings which were discharged to the tailings management area.

Milling during Phase II, since 1984, processed lower grade ores. Phase II tailings are neutralized to pH 8.0 and pumped to the tailings pond. A primary treatment system is used to settle solids and chemical precipitates prior to discharge of supernatant to a secondary treatment pond. Prior to discharge, effluent is treated with aluminium sulphate and barium chloride to precipitate radium-226. Final effluent is then discharged to Snake lake, which flows into Island Lake, thence through a fen area and ultimately into Sandy Lake.

Effluent discharges have met limits contained in *Metal Mining Liquid Effluent Regulations*, as well as limits in the site license for selenium, uranium and vanadium, thorium-230 and lead-210. Level of compliance with ammonia requirements is unclear due to field pH and temperature conditions.

Conclusions and Recommendations

- Effluent receiving environments have elevated levels of uranium, molybdenum, and major ions (calcium, magnesium, potassium, sodium) and sulphate. Uranium, molybdenum and nickel have been elevated in sediments downstream as far as Sandy Lake. These increases in contaminants are also reflected in higher concentrations of uranium, molybdenum, arsenic and radium-226 in macrophytes from Island Lake and the fen downstream, and higher uranium and molybdenum in fish. Receiving environment concentrations of ammonia are also a concern. The fen downstream of Island Lake

apparently protects downstream areas of Island Creek because most (96%) of the contaminants discharged are retained at that point.

- → It is recommended that ammonia, molybdenum, salinity and uranium be considered for inclusion in the revised MMLER, recognizing that salinity and uranium are largely specific to the uranium mining industry.
- → Monitoring for ammonia should include a consistent record ot both field pH and temperature

- Use of alternate technology for effluent treatment should be assessed as a possible means of reducing salinity. In addition, the regulatory requirement for radium-226 should be reassessed due to the large concentrations of reagent required to achieve required concentrations. However, effects due to treatment reagents need to be balanced with radiological risk to the receiving watercourse.

- Appropriate quality assurance programs are needed to ensure long term usefulness of data. Included in the quality assurance program should be a method to ensure greater accuracy in determining locations of sample stations, since "return to site accuracy" has been identified as a possible source of error. Changes in sediment sampling methods have also been a probable source of error.

5.2 Non-case Study Sites

5.2.1 Great Bear Lake, Northwest Territories

Monitoring was conducted in the area of a silver mine at Port Radium, which had previously been mined for uranium and radium. Tailings and other wastes were deposited directly into the lake. Concentrations of heavy metals and radionuclides in have been measured in sediments at 37 stations and in water at 6 stations in Great Bear Lake. Mercury levels in fish tissue have been measured in specimens collected adjacent to the mine site. Stations were located 0.01 to 2.0 km from the lake-based tailings.

- No evidence of contamination of water.
  - → Metals and radioisotopes in water were below detection limits

- Concentrations of mercury, lead, manganese, and nickel in sediments decreased significantly with distance from the lake-based tailings. Arsenic levels were low adjacent to the area of tailings deposition, and high in an area to the NE of the minesite. Most radionuclide levels (^{226}radium, ^{210}lead, ^{230}thorium), varied inconsistently throughout the study area, except for ^{228}thorium and ^{232} thorium which decreased significantly with distance from the mine and substrate organic content.

- Maximum concentrations of mercury (3.00 ppm), lead (1800 ppm), manganese (31,500 ppm) and nickel (590 ppm) were found at the area of tailings disposal. High levels of arsenic (2000 - 3700 ppm) were found NE of the minesite, with lower (400 - 1200 ppm) close to the lake-based tailings. ^{226}Radium maximum levels of 5×10^5 pci/kg were found; ^{210}lead, 9.1×10^5 pci/kg; and ^{230}thorium, 9.4×10^5 pci/kg.

- Mercury in lake trout muscle tissue ranged from <0.01 to 0.05 ppm, an order of magnitude below consumption guidelines.

5.2.2 Yellowknife Area, Northwest Territories

Gold has been mined from two mines in the Yellowknife area since the 1930s. In the ore gold is associated with pyrite and arsenopyrite, and problems of arsenic contamination in the Yellowknife area are well documented. Effluent from the mines has affected several small lakes (Pud, Kam, Meg, Keg and Peg) as well as Yellowknife Bay of Great Slave Lake. In addition, the area has been affected by airborne contamination from ore roasters historically used to separate the gold from the pyrite. Historical data was available, but recent data on Yellowknife is lacking in the AQUAMIN database.

- in 1978, average arsenic concentrations in surface water in Meg, Key, Peg and Great Slave Lakes: 2.0 mg/L, 1.9 mg/L, 0.7 mg/L and 0.02 mg/L, respectively. Con centrations of copper, and lead also elevated. Cyanide concentrations in Meg Lake 20 times Canadian Water Quality Guideline for the protection of freshwater aquatic life, but below detection limits in the other lakes.

- in 1978, arsenic concentrations in sediment showed a downstream decrease (Meg Lake - 539 mg/kg, Keg Lake - 349 mg/kg, Peg Lake - 76 mg/kg, Great Slave Lake - 12 mg/kg).

- in 1970's invertebrates, zooplankton and macrophytes collected in Kam and Keg Lakes showed high levels of arsenic. Sculpins (*Cottus cognatus)* sampled from Kam Lake had much higher arsenic levels (46 to 220 ppm) than those from control lakes (2.3 to 45 ppm).

5.2.3 Rabbit Lake Mine, Saskatchewan

Uranium mining at the Rabbit Lake Mine in northeastern Saskatchewan started in 1975. The mine is close to Wollaston Lake, and mine water and tailings tailings pond effluent drain to the lake by way of a series of small creeks and lakes.

- prior to 1985, effluent toxicity was attributed to high ammonia concentrations

- until 1981 concentrations of ^{226}Ra in water were 0.252 Bq/L in Pow Bay of Wollaston Lake, which receives run-off from waste rock piles. This concentrations was above Sask. Surface Water Quality Objective but below the Canadian Drinking Water Objective. After 1982, run-off was controlled and ^{226}Ra concentrations dropped to below SSWQO.

- in Hidden Bay of Wollaston Lake, which receives treated effluent, there were no discernable changes in radionuclide levels in bone andmuscle tissue of fish

5.2.4 Wekusko Lake, Manitoba

Wekusko Lake is southwest of Snow Lake Manitoba. The lake receives input from several different base metal mines. Close to the lake are the Anderson Lake and Stall Lake mines, which both deposit tailings subaqeously in Anderson Lake. Anderson Lake drains via Anderson Creek to Anderson Bay of Wekusko Lake. Further from the lake are the Osborne and Chisel/Ghost Mines.

- in 1983 all concentrations of all metals measured in Anderson Creek, Stall Creek and Anderson Bay were all well within the Canadian Drinking Water Quality Standards (1978) except for iron at one station in Stall Creek.

- the highest copper, zinc and nickel concentrations in sediment occurred in Anderson Bay while iron, manganese and arsenic concentrations were highest further from the creeks in Berry Bay. Copper averaged 112 ppm in Anderson Bay compared to 34 ppm in Berry Bay. Arsenic and manganese levels averaged 5.2 and 200 ppm respectively in the creeks compared to 19.3 and 560 ppm in Berry Bay. The most dominant metal in the sediments was iron at 30,800 ppm in the creeks, 38,800 ppm in Anderson Bay and 44,930 ppm in Berry Bay. No differences were noted between sampling area for Cd, Pb, Ni, and Hg.

- Environment Canada limits for fish tissue concentrations of Cu, Zn, Pb, As, and Hg were not exceeded in either flesh or liver from any of the seven species collected.

5.2.5 Namew Lake Mine, Manitoba

Namew Lake is approximately 65 km south of Flin Flon, just east of the Manitoba - Saskatchewan border. Advanced exploration for nickel-copper began in 1985, and construction of the effluent treatment system was completed in 1988. The mine was shut down in late 1993.

- water quality and sediment quality did not change significantly as a result of mining activity. Many of the minor changes which did occur could not be definitively linked to the mining activity. Conductivity and sodium concentrations did increase slightly as a result of mining activity.

- metal concentrations in fish tissue did not change asa result of the mining activity

5.3 Summary of Regional Findings and Recommendations

- Lead, zinc and cadmium are a concern at the Nanisivik Mine, although no relationship between the health or organisms and metal concentrations in water, sediment or tissue.

- Methods to control dust should be included in a revised Code of Practice for mines.

- Monitoring at Lupin and Nanisivik would benefit from developing and focusing on specific questions related to aquatic resource protection.

- Based on the findings of the Cluff Lake case study it is recommended that ammonia, molybdenum, salinity and uranium be included in the revised MMLER, recognizing that salinity and uranium are largely specific to the uranium mining industry.

6 Western Cordillera

6.1 Summary of Findings

6.1.1 Adequacy of Monitoring Programs/Some Findings from Case Studies

- Frequently the data base included many studies by different agencies with different objectives-a more comprehensive and integrated monitoring program is preferred. (Bell and Myra Falls case studies).

- There should be some form of commonality of monitoring program requirement, i.e. standardization of sites and methodology. (Bell case study).

- Some monitoring programs were limited in scope (eg. emphasis on water quality, limited biological studies). Also programs frequently lacked appropriate reference sites, adequate baseline information and employed inconsistent sampling protocols. This makes comparative assessments difficult and limits the ability to determine effects/impacts on aquatic organisms other than through inference. (Sa Dena Hes case study).

- Commonly lacking is sufficient frequency of sampling and coordination of monitoring sites, (eg. water quality, sediment, benthos, fish). Consideration must be given to both temporal and spatially defined reference sites in the design of monitoring programs. (Bell case study).

- Some operations were not initially designed for a positive discharge, accordingly there was an inadequate or non-existent pre-operational database with which to assess impacts resulting from changes to the mine plan. There needs to be a basic baseline monitoring program conducted to anticipate changes to the mine plan. (Bell and Brenda case studies).

- Three of the four case studies were conducted on mine sites that were subject to the MMLEG. In addition, these mining operations were subject to a more stringent regulatory requirements from the province of British Columbia. Hence, the ability for MMLER to have an effect is limited. (Bell, Brenda and Myra Falls case studies).

- Difficulty in meeting stringent water quality criteria/objectives (eg. Mo) requires a water, sediment and biological baseline data base what is capable of early detection of effects. (Brenda case study).

- Government review and feedback on environmental monitoring programs is not always timely, and therefore problems are not always recognized as soon as they should be. (Myra Falls case study).

- The use of Benthic Invertebrates monitoring was included in all case studies. Gross effects were documented, however, more subtle effects are difficult to determine. Methodological consistency and fundamental understanding of the dynamics of the populations made the interpretation challenging at lower resolution. (General observation).

- Both metal concentration in fish tissues and population surveys were reported in some of the case studies. Elevated tissue metal levels were identified in two cases. In most cases fish population surveys were limited and variability in fish community composition due to chemical factors were often confounded by other factors such as resource harvesting and habitat disturbance (eg. flow reductions) factors. Small systems are more prone to these fluctuations. Resolution can sometimes be improved by employing longer term sampling. (Bell and Myra Falls case studies).

- Several contaminants were found to have effects in the receiving environment at the same level of resolution as the current analytical methods.

- Baseline studies were often not sufficient to describe the temporal and spatial variability. The lead time to implement such studies weakens the ability to perform robust impact assessment. (Sa Dena Hes case study).

- Methodologies for various parameters differed, sometimes substantially, from study to study. Flexibility allows to target a specific question where standardization allows for comparisons between studies. (General observation).

- Very few studies provide sufficient quality control and quality assurance in the data provided. Laboratory results are now routinely performing this type of check but it is seldom reported. Field data falls behind. (Brenda case study).

- Statistical analysis of the information has usually provided care in avoiding type I error (find a difference when it does not exist) but study design provided little care in avoiding Type II error (finding no difference when one exists). (Brenda and Sa Dena Hes case studies).

- Baseline information for the metal concentration in tissue is usually lacking. Tissue reference levels for mineralized and pristine environments should be provided. (General observation).

- Toxicity tests should be applied appropriately; acute toxicity tests are not appropriate for receiving environment evaluations. Proper end-points for the system need to be determined. (Sa Dena Hess, Myra Falls and Bell case studies).

- Quality assurance and quality control in the collection of biological information are required to confirm reliability and transferability of the data. (General observation).

- methodologies should be standardized for routine collection of information. Adaptation of a methodology should be performed only to address a specific question. (General observation).

- lack of baseline information and natural variability within populations prevent conclusive statement about impacts. (General observation).

6.1.2 Effectiveness of the MMLER

- Certain metals (eg. Mo) contained in mining effluent can be more critical to livestock or wildlife species than aquatic biota. The MMLER's primary purpose is protection of aquatic resources (eg. fish) and although contaminant controls may be possible through other legislation (eg. CEPA/CEAA) and other jurisdictions, the MMLER does not (nor was it intended to) regulate for the protection of livestock or wildlife species. (Brenda case study).

- The case studies identified several substances of concern which are not currently regulated in the MMLER. These include cadmium, molybdenum, nitrates and cyanide. Consideration should be given, where applicable, to including these substances under the Regulations.

6.1.3 Recommendations to Improve Monitoring Programs

- monitoring programs/data must be supported with appropriate QA/QC in order to reliably detect subtle changes in water quality prior to exceeding receiving water quality objectives/criteria.

- Sufficient baseline replicates for sediment and benthic macro-invertebrates must be collected in well-defined deposition areas to enable detection of possible biological effects before they occur.

- Monitoring programs should be accompanied with appropriate triggers to alert mine

managers and regulatory agencies when action is required.

- The study design should specify the level of change to be detected for biologically relevant parameters. Power analysis should provide feedback on the economical feasibility, choice of parameter, and size of difference to be detected.

- Sampling frequency should be adapted to the variability of the system rather than set at a fixed schedule. Re-distributing sampling effort into time strata to provide the same coefficient of variability seems to be the most appropriate allocation of resources and at the same time increase the information level of the data

- Information from the receiving environment should be fed back to the mine operation for decision making. This feedback loop should allow for a quick response about the effect the mine has on the environment.

- The quality of pre-mining background water and the ameliorating factors such as metal-complexing capacity should be included in the baseline monitoring program and be considered in assessing the impacts and regulatory requirements of mine applications

- include a proper choice of sampling stations, adequate sampling frequency, use of appropriate analytical techniques for measuring specific parameters, consideration of chronic as well as acute effects and to determine the fate and transport of metals.

- in the case of particularly sensitive systems, emphasis should be placed on studies of chronic effects which would include, as appropriate, laboratory and field mesocosm investigations.

- Parameters selected for monitoring should target the expected effect and additional parameters which may be affected. Selection may be achieved by completing a modified risk assessment.

- Feedback by regulatory agencies on the results of the EEM program must be provided to the company on a regular and clearly understandable means so early and appropriate remedial action can be taken if necessary

- Monitoring program should not be overly onerous; a well-designed program with a few, well-chosen parameters and the resultant data stored in an easily viewed database can provide an effective monitoring tool and can permit a timely response to potential problems.

6.1.4 Suggested Research Needs

- Additional research is required on chronic and sublethal toxicity effects of metal contaminants and on the application of methods such as mesocosm, MIMS (Molecular Indices of Metal Stress), metallothionein to assess more effectively sublethal and chronic effects.

- Lack of fundamental understanding of dynamic changes in populations and the significance of the changes prevent definitive answers. Population evaluation relies on a body of evidence rather than single studies. More work needs to be done to determine the boundary of natural variability in a population which would constitute a threshold for the health and survival of that population.

6.2 Reviewers Comments on Individual Topics

Numbers used in these comments refer to document numbers in the AQUAMIN database.

6.2.1 Water Chemistry (Chris Mills)

The AQUAMIN Part II study is concerned with the *aquatic effects of metal mining activities in Canada.* An effect is the result of a cause, and an effect for the purposes of this report should be statistically valid and measurable. Minerals and mineral deposits cause effects in the water chemistry in and around them (*e.g.*, natural acid rock drainage and heavy-metal transport in the Macmillan River (108)), but such natural effects, regardless of their magnitude and extent, are not effects of mining activity. Rather, these effects are a natural part of the baseline water chemistry prior to any mining activity. The definition of mining activity cannot be completely objective but, for the purposes of this report, mining activity will include exploration activity only where the latter contributes effluent to a natural system (*e.g.*, from development work such as adits – Tom Property, Macmillan Pass (180) and Jason Property, Macmillan Pass (181)). Effects of mining activity may be positive or negative, and may be benign or deleterious from a biological viewpoint. Other reviewers have considered biological effects.

The water-chemistry review consists of a summary of water-chemistry data from 45 documents on mines, abandoned mines, tailings dumps, exploration sites, proposed minesites, and watercourses and lakes in Yukon Territory and British Columbia. The review for Yukon Territory covers 9 specific sites, and the review for British Columbia covers 18 specific sites. Information contained in the original reports was derived from sampling programs that varied from one-day site visits, to the extensive reporting for the Bell Copper

(273 and 274) and Brenda (374) closures, the Equity Silver closure Eskay Creek development (244 and 245), and the British Columbia Ministry of Environment review of the Westmin Resources Myra Falls operation from 1965 to 1981 (10, 11 and 12).

The reports range in publication date from 1975 (*i.e.*, pre-MMLER) to 1993, during which time the technical parameters of the assessment of environmental impact have changed substantially. Technical changes have included more reliable sampling and analytical techniques, the lowering of detection limits (as reflected in the standardized, referenced, and described procedures in the reports), the distinction between total and dissolved or extractable metals and, more recently, the study of speciation, chelation, and complexing capacity [as in the Bell Copper closure (274) and Eskay Creek development (245)]. Legislative changes (other than the MMLER) and changes in various agency guidelines have included increases in the number of parameters monitored, more frequent monitoring, and reduction in acceptable contaminant levels for effluent, drinking water, irrigation water, and aquatic life.

The reports vary widely in the quality and quantity of data, and in the usefulness to MMLER evaluation. In fact, none of the reports evaluated made specific reference to the MMLER. There is considerable variation in the types of effluent examined, which include tailings-pond decant, seepage, run-off from waste-rock piles, and natural and treated acid rock drainage (ARD). A consistent omission from reports on minesites is the nature of mining activity with regard to effluent generation, making difficult a determination of the causes of effects.

The reports indicate clearly that mining activity causes water-chemistry effects (benign or active biologically) in downstream waters. The magnitude and extent of these effects depend upon several factors:

- the elements or chemical compounds (anions and cations) involved. Oxidation potential and pH usually control ionic solubility and therefore the distance of transport (extent). The degree of metal complexing by ligands is also pH-dependent

- the design, operation, and management of the mine. Post-closure management is essential. The effects of abandonment are clearly seen for Mt. Washington (6 and 32), whereas the reduction of effects by post-closure management are evident for Cyprus Anvil (185)

- the precipitation cycle at the minesite, and the seasonal variations in the flow rates of natural watercourses (*i.e.*, temporal variations in flows in relation to temporal variations in effects).

Few of the reports reviewed contained such information, and any study claiming to be "baseline" must contain pertinent data for those subjects. Of the reports reviewed, only ten

contained valid temporal within-station data (Myra Falls (416 and 404), Mt. Washington (6), Endako (292), Equity Silver (283, 385 and 25), Bell Copper (274), Eskay Creek (245), and Brenda (374)). In general, sampling and analytical techniques were standardized, well-defined, and referenced or described. The determination of low-level mercury, as in the Cinola studies (239 and 382), is a possible area for future R&D. Metal-complexing studies (as for Bell Copper (245 and 274), and Imber (1991) must be considered to be in the development stage, and studies correlating biological effects with degree of speciation are required to develop a better understanding of the subject.

Reported QA/QC and statistical evaluation have increased in the more recent reports, but standardization is required in this field. Finally, the only way to ensure that measured water-quality parameters are an effect of mining activity (*i.e.*, mining activity is the *cause* of the *effect*) is to establish baseline data before mining activities commence. In the reviews, individual reports suitable for future case studies have been identified where appropriate.

6.2.2 Sediment Chemistry (John Kwong)

Twenty-seven documents of relevant sediment-chemistry data were reviewed. The time spent in reviewing each report varied with the extent to which the contents of the report fit the AQUAMIN assessment criteria.

From the sediment-related information presented in the reports, it is apparent that the process of mining inevitably affects the physical and chemical properties of sediments in the receiving water bodies (Fording Coal (33), Barlow Creek (178), Equity Silver, (235), Brenda (374) and Bell Copper (273)). For metal mining other than placer operations, the assessment of effects has been focused on measuring changes in the metal concentrations of sediments in the water bodies receiving mine effluent. Satisfactory quantification of the magnitude and extent of such changes, however, has not been achieved for most minesites. Major difficulties encountered are as follows:

1. *Lack of appropriate reference station(s)/data for detecting changes.* Ore-forming processes are highly varied, and it is not uncommon to find natural mineralization that is in the vicinity of a minesite but outside the mine boundary. Thus, it is not always possible to establish a control site which has so-called "natural" background metal concentrations. Reference sites too distant from areas of potential mine influence may not have the same lithological and biogeochemical setting (*e.g.*, Cariboo Quartz Gold (22). By the same token, comparison with global or regional average soil/sediment metal concentrations is not really meaningful. The best control data seem to be pre-mine baseline concentrations at a suite of sampling sites near a mine development. Such information is generally lacking for most older and closed mines. It is a recent trend that

regulatory agencies as well as the mining industry are collecting such data at potential minesites prior to development (*e.g.*, Howard's Pass (174), Tom Propery, Macmillan Pass (180), Jason Property, Macmillan Pass (181), Cinola (234 and 237) and Sa Dena Hess (566).

2. *Sampling problems.* Sediments, especially along streams, are usually heterogenous in nature. It is not easy, therefore, to obtain a truly "representative" sample at a particular site. Significantly different results from the same sampling station are commonly reported when different sampling methods are used (*e.g.*, Cinola (237)). Lake-sediment sampling requires special equipment and thus is expensive. Generally, analyses of only a few cores are used to infer the physical and chemical properties of sediments over a large area (*e.g.*, Bell Copper (274), Brenda (354) and Cyprus Anvil (177)). Furthermore, temporal variations in the composition of lake and stream sediments are commonly observed (*e.g.*, Cinola (234)). A comparison of analyses derived from samples collected in different seasons may not always be valid.

3. *Influence of the geochemical properties of individual metals.* Depending on the geochemical behavior of the metals involved and the local biogeochemical setting, some elements are more mobile than others in a given environment. Thus, it is not surprising to find a mobile metal, such as Zinc or Cd , more depleted in sediments at a station closer to the source than at a farther station (*e.g.*, Brenda (374)) . Unless mechanical transport is the only mechanism of contaminant transport in a receiving water system, conclusions on changes in sediment chemistry cannot be made without taking into consideration the associated water chemistry and geochemical behavior of the metals concerned.

Inasmuch as only the bio-available portion rather than the absolute concentration of metals released from the mining process will affect the health of the local ecosystem, more recent investigations on metal contents of sediments also address the issue of speciation of the component metals. Many of these investigations involve elaborate sequential extraction analyses to determine how easily a particular metal will be released from the solid phase and become bio-available (*e.g.*, Cariboo Quartz Gold (22), MacMillan Pass (107) and Bell Copper (273). To date, different schemes have been applied to analyze sediments from different sites. For future comparison, it is desirable to develop a relatively simple and cost-effective sequential extraction procedure which could be applied industry-wide to determine the bio-availability of the relevant metals. In this regard, the grain size of the "refractory" or "residual" fractions should also be ascertained because the contained metals can be made bio-available upon alteration of the fine-grained host by physical, chemical, or biological reactions. In conclusion, the current database on sediment chemistry allows only qualitative statements to be made regarding the effects of mining on the receiving waters; quantitative estimates of the magnitude and extent of the effects are generally not possible for most minesites.

6.2.3 Toxicity (Benoit Godin)

The toxicity assessment consisted of the review of information from documents contained in the AQUAMIN database. Thirteen documents were reviewed. The testwork methodology, and the extent and magnitude of effects, were evaluated. Some general observations can be made:

1. *Lack of complementary chemistry with toxicity testing.* Very little chemical information is provided with the toxicity tests. This observation particularly applies to the older studies. The more recent studies usually provide chemical data, but commonly it is limited to analysis of MMLER parameters. The relationship between the chemical causative agent and the biological response of the test should be matched more closely. The interval between the time of sample collection and bio-assays is rarely reported, but the chemistry may change between these two events. In addition, only rarely is the full chemical composition of a sample given (cations, anions, and chelators). Typically, only metals (cations) are determined, thus preventing speciation modelling to determine the free metals, which are more likely responsible for acute mortality rates.

2. *Mortality reporting.* Although the reporting of mortality tests commonly has been limited to pass or fail, not only are the recent reports more complete, but attention to QA/QC procedures is becoming the norm.

3. *Placer and smelter toxicity studies have little relevance for the AQUAMIN review.* The mechanism of toxicity in placer and smelter environments is different from that related to metal-mining liquid effluent. In the reports on placer operations, the chemical component of the substance has generally been ignored because toxicity is assumed to be related to physical effects such as abrasion or clogging of the gills. The reports involving smelter slag and toxicity add to the confusion because it is suspected that both mechanisms (physical and chemical) act at the same time. For the purposes of toxicity evaluation, placer and slag discharges should be treated differently from liquid effluents.

4. *Recent efforts in toxicity.* The field of toxicity research is in rapid evolution. In the past the only test routinely performed was 96-h LC_{50} for rainbow trout, but there are now new test species with which to measure different trophic levels. Each test has its own merits and problems. The toxicity test end-points have also evolved from acute-toxicity tests, to chronic, to sublethal, to expressions at the population level (mesocosm testing). New media are also being used (*e.g.*, sediments). Assessment and interpretation of effects are more on the basis of a body of evidence than on individual test results. These new developments are attempting to address biological concerns in the disposal of wastes.

6.2.4 Benthos (Jenifer Hill and Bob Hallam)

The 32 reports presented for review comprised a broad assortment of studies which included some excellent reports with detailed analyses on environmental effects, some with adequate data but very limited analysis, some with only baseline data, and others with very limited data. In most cases it was difficult, if not impossible, to determine environmental effects, partly because of the high natural variability in benthic communities, and partly because of insufficient analysis of the data. Substantiated effects were usually found in reports containing a well-designed sampling program and statistical procedures to determine significant temporal and spatial differences.

Effects, relative to reference sites, were observed at the following mines:

- at Endako (2), benthic communities changed downstream of the tailings dam because of changed physical parameters and the presence of iron precipitate
- the Mt. Washington (6) site had degraded invertebrate populations containing only two orders of insects in the direct pathway of contamination, as compared with high diversity at the control sites (but data analysis was sketchy)
- the Venus (175) mine outfall resulted in reduced benthic diversity, likely the result of elevated levels of Zn and Pb in sediments; the reduction seemed to be restricted within a 1-km radius of the tailings, and was not observed 3 km from the tailings
- Keno Hill (170 and 173) benthic communities had reduced diversity, but the cause could not be determined from the sample locations
- effects of the Cyprus Anvil (172) mine resulted in changes in benthic community as far as 10 km downstream; the likely main attribution is effects from the decant and some of the seepages
- Mount Nansen (182) studies indicated reduced benthic communities downstream of the tailings decant

On the basis of the reports reviewed, either no effects or improved benthic communities were observed for the following mines:

- Brenda (396) showed no effects in 1991 (one study), but there were no direct discharges from the minesite; results from an extensive study released in 1993 (374) were inconclusive

- Cyprus Anvil (185) showed increases in species abundance in benthic communities in comparison with results from previous studies

- Arctic Gold and Silver (418) showed little evidence of effects originating from the site of the abandoned mill Throughout, however, there is an apparent lack of standardization in sampling equipment, mesh size, sampling techniques, sampling period, number of replicates, level of taxonomic identification, and data analyses (counts, tolerance levels, diversity indices, richness, evenness, power analyses, cluster analyses, *etc.*). The spectrum of receiving environments was also extremely broad, and included streams (alpine to floodplain), rivers, lake foreshore, lake bottom, and marine foreshore sites. Further, there was little, if any, correlation with receiving water or effluent quality at sample sites.

Most of the studies reviewed were simply a one-time assessment of effects. More regular biomonitoring programs, however, were completed for 4 of the 17 mines reviewed, including Equity Silver, Bell Copper, Cyprus Anvil, and Endako.

Any future benthic macroinvertebrate monitoring program, whether it be for documenting baseline conditions or effects from operations (*e.g.*, EEM), should include a well-designed standardized program. As a minimum, this program should incorporate historical sample locations, mine and mill layout, control sites, sample replication, estimates of available dilution, habitat composition, and proposed analytical techniques. Where adequate data are available, statistical tools should be utilized to determine "significant" spatial and temporal variations using Analysis of Variance, linear trend analysis, or other statistical tools as appropriate. Statistical analysis should be carried out only if the statistical assumptions are met. In situations where a statistical procedure is not used, densities and a suite of indices, which include diversity, evenness, richness, dominance, and similarity, can be used to provide a better representation of community structure. Analyses should also review species composition and habitat preferences to help in the interpretation of effects.

6.2.5 Zooplankton, Phytoplankton, Macroinvertebrates (Dave Sutherland)

Only 10 reports were available for reviewing the effects that mining has on aquatic plants. Generally, aquatic plants have not been used to assess the effects of mine-waste disposal because:

- non-rooted aquatic plants are not as sensitive to metals as are many vertebrates and invertebrates

- non-rooted plants are generally not exposed to the highest metal concentrations in the aquatic environment because of high mobility (plankton), short vegetative life-cycles, and exposure to aqueous, but not sedimentary, sources

- changes in aquatic non-rooted plant communities have been difficult to detect because of high variability in substrate materials (periphyton), and because of the variability of conditions, such as wind and solar radiation, that affect plankton

The use of stream mesocosms, or artificial streams with controlled additions of waste, was successful in indicating the dilution required to prevent effects from acid mine drainage, and in demonstrating the greater effect of combinations of various metals relative to what might be expected from single-metal exposures. Artificial substrates have been used to assess the effects of mill-effluent discharges on periphyton but, as is commonly found, the effects of nutrients from domestic wastes, fertilization of reclaimed land, and blasting are more pronounced than that of metal toxicity, and may serve to mask the effects from metal uptake. The effects of nutrients on biomass and community diversity may be significant where nutrient balances, usually determined by phosphorus availability, enable the plants to use these nutrients.

Studies using direct sampling of periphyton or plankton were most commonly ineffective because of failure to adequately control temporal and spatial variables. In these studies, inadequate replication and lack of *a priori* statistical design also reduced the sensitivity of detection of significant effects.

One study (Myra Falls (404)) of effects on phytoplankton demonstrated that species dominance changed with decreasing metal levels. This study is a good example that qualitative information on community composition can be a useful addition to the quantification of community densities, biomass, and species diversity which is most frequently used. As long as sampling techniques are comparable, long-term monitoring of community composition may be necessary to detect effects that are subtle.

Judging from the minor amount of monitoring aquatic plants that has been done, monitoring programs of more rigorous design and longer term, coupled with the use of mesocosms and other experimental exposures, should be put to more effective use to evaluate metal and nutrient effects in British Columbia.

6.2.6 Fisheries - Chemical Analysis of Tissue Residues or Physiological Indicators (TR) and Assessment of Fish Populations or Communities (PC) (Wayne Knapp)

The twenty three reports reviewed were varied in their information about fish populations and metal levels in fish tissues. The reference data base provided more than one report for only three mine sites: Equity Silver (244, 245 and 286), Brenda (356 and 374) and Myra Falls (26 and 404). Reports on the former two mines provided the most comprehensive data on fish populations; these, together with the Myra Falls studies, provide the most extensive reporting of metal tissue concentrations directed specifically at assessing mining activities. Because of the relatively extensive data base they provide, these three mine sites are considered to be the most appropriate candidates for more intensive assessment (ie. case studies). The reviewer encountered some difficulty in relating changes in fish populations and metal tissue levels to mining activity, since the review was limited to only those two specific aspects of the reports. Detailed data on effluent chemistry/toxicity and receiving water quality was not reviewed. Consideration of such information is essential when interpreting the effects of mining activity on fish populations and metal uptake.

In terms of fish population studies the "Equity Silver" mine reports (244, 255 and 286 - Eskay Creek reports were included herein, since the proposed mill was located in the same watershed as the Equity Silver site) included some of the most comprehensive studies on fish (rainbow trout) populations. The Equity studies included detailed fish population estimates at two sites. Assessment techniques included the use of fish tagging methods. The studies concluded that fish populations were relatively constant over an eight year period; variations in fish populations were attributed to physical habitat changes and artificial stocking programs rather than effects from the mine effluent discharge. A more rigorous review of the mine effluent quality, in conjunction with the fish population study results, is necessary to confirm the report conclusions The Brenda mine studies (356 and 374) utilized electro fishing and multiple removal-depletion methods to assess fish populations.

The reports noted some differences in fish species and fish populations in the streams and stream reaches studied. However, it could not be clearly demonstrated whether these differences were related to mine discharges, natural habitat limitations, or to physical habitat disturbances (eg. stream diversions, reduced water flows). Some stream sections had been subjected to periodic channelization which resulted in substantially reduced fish habitat diversity.

The "Equity Silver", Brenda and Myra Falls mine reports provided the most extensive information on tissue metal levels related to mining activity. Some indication of metal uptake (eg. copper and zinc) was noted in the case of the Equity Silver site although the specific causative mechanism was not offered; both muscle and liver tissue metal levels were generally

within the range observed elsewhere in British Columbia. The Brenda studies concluded that metal levels in fish from below the mine were less than or equal to those in fish above the mine influence, suggesting that the mine has not had an obvious effect on tissue metal concentrations.

The Equity Silver and Myra mine studies also included measurements of hepatic metallothionein in fish (rainbow trout). The Equity Silver studies found that metallothionein levels did not differ appreciably from those at reference sites where metals were not elevated; the Myra studies reported a downward trend from the most to the least contaminated lakes in terms of zinc in receiving waters, of cadmium and copper in high molecular weight fractions, and of copper in low molecular weight fractions and metallothionein. The report suggests that metals in livers of exposed fish are a poor measure of metal effects because, in this case, they exhibited extreme variation within a single sample site and zinc (the predominant metal in the water) did not differ in the livers of fish from the most contaminated lake to the least. Metallothienein measurements should be included in conjunction with tissue metal concentrations for impact assessments of mining, or other activities, where sublethal concentrations of metals are involved.

Many of the other studies (eg. Mount Nansen (182), Keno Hill (173), Venus (175) and Cariboo Quartz Gold (250) included some limited fish capture information. However, in most cases the studies were not specifically designed to characterize fish populations, or to assess the effects of mining developments on fish populations, but were a means of collecting fish for other purposes (eg. -metal tissue analysis). At best they provided limited insight into the presence or absence of fish at specific sampling times. While these studies were superficial in terms of fish population assessments, some (eg. Keno Hill (173)) suggested that fish captures were significantly reduced immediately below mine effluent discharges, although it could not be conclusively shown whether this was related to commensurate reductions in fish food, adverse effects of acutely lethal effluents, or other factors.

Some studies assessed baseline conditions (e.g. Minto (171) and Howard's Pass (174)) in the vicinity of proposed mining operations, and therefore could not be used to assess the effects of mining activities. Other reports (eg. Liard River (379), Thompson River (237), West Coast, Vancouver Island (422) and Yukon Territory (183)) considered metal concentrations in fish tissues from a variety of sources. However, many reflected areas not related to mining. Accordingly, while the techniques used in these studies may be of some use in designing Environmental Effects Monitoring programs for the mining industry (eg. types of tissues to analyse), and in comparing results to reference areas, they also are of limited value in directly assessing the effects of mining activities.

Several studies (eg. Bell Copper (273) and Cariboo Quartz Gold (250)) provided evidence that certain biota/tissues (eg. zooplankton, fish) accumulated metals (eg. mercury). Studies

were however, somewhat limited in documenting any long-term trends or relating the source of metals specifically to mining. One research study (Cinola (218)) indicated possible accumulations of mercury in fish (salmon) eggs in preliminary studies, but these findings were not confirmed in later work. Nevertheless, the appropriateness of metal uptake in fish eggs should be further considered as an impact assessment tool for specific situations.

7 General Observations about the Effectiveness of the MMLER

7.1 Scope/Application

- The intent of the MMLER is to limit the discharge of deleterious substances from base metal, uranium and iron ore mines only. It does not include gold mining operations or refineries that utilize the cyanidation process. This can in some cases result in an inconsistent application of regulatory approaches between gold mines which use conventional recovery processes (ie. flotation) (subject to the MMLER) and those that use cyanidation (subject to general provisions of the *Fisheries Act)*. [Since 1977, Canadian cyanidation processes have been regulated in Canada under Provincial Certificates of Approval (C of A).]

- In the Explanatory Notes of the MMLER and the MMLEG, the Regulations limit concentrations of specific contaminants in effluents, and define the frequency of monitoring and reporting. Contaminant loading (i.e. sediment metal accumu'ations) are not accounted for in the MMLER. [Contaminant loadings are reported for some sites under Provincial C of A's.]

- The "operations area" referred to in the MMLER includes items such as ore storage areas, active and abandoned waste rock dumps, active and abandoned tailings impoundment areas and treatment ponds, cleared or disturbed areas adjacent to those places, structures or areas and ditches, watercourses or water bodies the character of which have been altered by mining activity. The flow measurement, sampling and reporting requirements of MMLER are directed solely to the undiluted effluent discharged from the operation and do not take into account the assimilative capacity of the environment. Other sources (i.e. seepage and non-point) of contaminants that may contribute significantly to mining impacts are either excluded or not included in assessments/investigations pursuant to the Regulations. [These sources are regulated under Provincial Regulations.]

- The MMLER do not apply to decommissioned/closed operations; whereby, impacts can continue during periods when mine production has ceased and follow-up monitoring and controls may be required. [Decommissioned/Closed operations are regulated by the Provinces.]

- The MMLER are based upon Best Practical Technology (BPT) and on chemical contaminant (limited parameters) and do not specifically address physical mining related-impacts (eg. physical land disturbance, alterations of stream flows). Not only can these factors have a direct impact on aquatic resources, but reduced stream flows can aggravate effects of effluent constituents (eg. metals) through reduced dilution.

- In the Explanatory Notes for the MMLER and MMLEG, the aim of the MMLER and MMLEG is to ensure that all base metal, uranium and iron ore mines operating in Canada apply Best Practicable Technology (BPT) to the control of their liquid effluents. The term BPT implies technology both technically and economically viable.

- The MMLER apply only to the quality of effluent, assimilative capacities of receiving waters are not considered. Without a special regulation, the release of effluent is not prohibited.

- The MMLER focus on BPT and "end of pipe" control of "deleterious" substances and while they include requirements for effluent monitoring they contain no requirements to monitor the effects of the mine on the receiving environment nor the effectiveness of aquatic resource protection. Frequently, these factors are implemented by other jurisdictions.

7.2 Jurisdiction

- The Explanatory Notes of the MMLER indicate that in specific locations where they [MMLER] fail to protect the fishery resources, more stringent requirements may be imposed by the federal government through a specific (i.e. site specific) regional regulation. To date, there is no evidence of that provision/intent ever been undertaken, although a Special Regulation was developed for the Amax-Kitsault mine in British Columbia that allows it to discharge tailings directly to the receiving environment. Generally, if more stringent requirements are needed to protect the environment, these are achieved through water licences north of 60^0 or through more stringent provincial regulations.

- MMLER were intended as a national standard, and in certain situations are too broad adequately protect local receiving waters. Provision is made for more stringent site specific controls if required; this can only be achieved through complex, time consuming Order-in Council. This action has not been used. Alternatively, other government jurisdictions must be relied upon.

- AQUAMIN study may be biased because aquatic monitoring is only done on sites where aquatic effects are likely.

7.3 Parameters

- The MMLER numerical limits for arsenic, copper, lead, nickel and zinc are expressed in terms of "total metal" concentrations which include these metals in both their dissolved and solid forms. Only in the case of Ra^{226} has a parameter been set as a soluble form since the practice within the uranium industry has been to analyze for dissolved Ra^{226} after filtering the sample through a three micron-filter rather than for total Ra^{226} values. [In general, dissolved forms have a higher mobility in the watershed prior to dropping out; whereas, solid forms are particulate bound and drop out much closer to the point source.]

- In the Explanatory Notes to the MMLER, controls were not set for mercury (Hg), cyanide and oxidizable sulphur compounds (thiosalts). The Notes indicate that:

  1) A review of the treatment of cyanide as a leaching agent was in progress. [From the case studies, three different cyanide destruction technologies are in place.]

  2) A thiosalts inventory was available and that a removal technology for thiosalts was under review.

  3) A working group would be formed to review mercury concentrations in mine effluents, formulate BPT, and suggest control standards.

- Since the development of the MMLER Hg has been declared CEPA toxic, there are no limits for Hg. Provincial limits exist under the C of A's.

- The Explanatory Notes state that many other constituents exist in mine effluents and have not been controlled. The Notes declare that mine operators should make special efforts to minimize discharges of the following substances:
  - oil, petrochemicals, or other immiscible substances
  - ammonia and other nutrients (*e.g.* nitrates)
    [A consortium led by CANMET has been established to look at technologies for ammonia. From the case studies, some mines have established source reduction programs for ammonia. There are provincial limits established with the C of As.]
  - sulphates
  - ferrous iron and other oxygen demanding substances
  - toxic reagents or reagents of unknown toxicity

- The MMLER place a minimum limit on pH. Mining effluent can also pose alkalinity problems (ie. high pH) which are not addressed in the MMLER requirements. Certain substances (eg. ammonia) are more toxic at higher pH levels and high pH effluent can, in themselves be acutely toxic. The need to include an upper pH limit (and ammonia) in the MMLER should be considered. The applicability of existing guidelines (eg. DFO Guidelines for the Use of Explosives in Canadian Fisheries Water) should be considered in this regard.

- The MMLER do not control water usage, stating only that water usage in mines should be minimized. Mine operators are required to report the monthly volume of each effluent discharged.

- Currently there is no provision for mine effluents to be non-toxic (Guidelines only). As a minimum non-acute lethality is considered necessary for basic protection of aquatic resources, particularly where important resources are located immediately adjacent to the discharge(s).

7.4 Monitoring and Assessment

- There is no requirement for QA/QC of data obtained from the actual analyses of samples taken. Without this information, the reliability and usefulness of some monitoring data are questionable as use in determining impacts of mining effluents.

- In the early days following promulgation of the MMLER, there was inadequate assessment of existing mines and lack of required monitoring of the receiving environment that may have resulted in delayed recognition of problems and unnecessarily prolonged continuation of effects.

- Effluent discharges increased the concentration of some substances downstream. It was generally difficult to determine the significance of such changes and to differentiate any recorded increases from those resulting from natural variability. The degree of available dilution and effluent concentrations of contaminants were two complicating factors.

- Regulatory limits were primarily defined for effluent discharges. Often water quality criteria or objectives were used in attempts to describe impacts on receiving waters. However, in some cases natural elevated background levels and particular receiving water quality characteristics complicate the application of standard water quality guidelines.

- Monitoring programs should be accompanied with appropriate triggers to alert the mine managers and regulatory agencies when action is required.

- There is no associated requirement for sediments, in terms of looking towards sediment quality criteria. Criteria have been/are being developed with the USEPA, B.C. MOELP, Ontario MOEE amongst others. The need for sediment criteria will provide additional information in terms of the cumulative effects of the total loading of the discharged deleterious substances from the operations.

- Collection of baseline data is currently not a requirement of the MMLER. However, baseline monitoring may be required under the Canadian Environmental Assessment Act (CEAA) and is frequently required as part of provincial mine review processes. The need to include such requirement under the MMLER versus harmonization with other legislation/jurisdiction should be considered.

- Water quality in the receiving environment is often verified against the CCREM guidelines. Often mines are developed in mineralized areas where background water quality exceeds these guidelines. The lack of an appropriate "trigger" for use in designing monitoring programs, verifying impacts and determining the need for action is sometimes a problem.

- Sediment quality criteria are presently non-existent. Sediment has the opportunity to integrate with contamination over long periods of time through surface adsorption. Currently only contamination over background levels can be determined, its significance cannot be determined from chemical analysis alone, but in conjunction with benthic invertebrates, and sediment bioassays (ie. Sediment Triad).

Appendix 1: Working Group Members

Working Group 3

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Working Group 6

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Note: Some participants joined their respective Working Group after the group had started its deliberations; others left before the group had completed its work. Hence, participants were not necessarily involved in all activities and decisions of their respective Working Group

Appendix 2: Working Group 6 Review of Database Documents

The evaluation of reports listed in the database was conducted with regard to the objectives of AQUAMIN. In addition, WG 6 used this review as a screening process for data and information in the selection of sites or mines for case-study evaluation. The data assessment was as outlined in the framework for examination of aquatic effects of metal mining activities. The reviews consist of a summary of topic data from documents on potential, operating, and former mines, on tailings facilities, exploration sites, and watercourses and lakes in British Columbia and Yukon Territory. Distinctions were drawn between those reports which were clearly within the scope of the AQUAMIN terms of reference, and those whose relevance to AQUAMIN was questionable.

The review covers documents for fifteen specific sites in Yukon Territory, and for twenty-three in British Columbia. Table 1 shows a summary of reports (documents) and topic reviews by number and by minesite/location. The format of Table 1 is that recommended by Working Group 1 in the Criteria Document, **but it must be noted that Table 1 shown here is compiled from the individual reviews of Working Group 6 and not from ratings in the AQUAMIN Database**. Table 1 is divided into two sections. The first section summarizes reviews of sites that fall clearly within the AQUAMIN terms of reference, whereas the second section summarizes reviews for sites not within the terms of reference, and for documents that should be excluded on the basis of the Criteria Document. The criterium used to assign exploration sites to one section or the other was the presence or absence of development work such as adits that released effluent to the environment. Presence justified inclusion in the terms of reference, and absence justified exclusion.

The documents reviewed range in publication date from 1975 to 1993, a period of nineteen years, during which the technical, administrative, and legislative parameters of the assessment of environmental impact have changed substantially. Mining in British Columbia and Yukon Territory has also been, on the whole, subject to two different sets of legislation: Yukon mines are subject to the MMLER and Territorial regulations regarding water use, and British Columbia mines are subject to the MMLER and Provincial regulations under the joint administration of the Ministry of Environment, Lands and Parks and the Ministry of Energy, Mines and Petroleum Resources. Technical changes have included more reliable sampling and analytical techniques. Among the administrative changes, responsibility for monitoring programs has shifted from government to the operator. Legislative changes have included increases in the number of parameters monitored, and more frequent monitoring. In British Columbia, Provincial discharge permits are issued on a site-specific basis.

Table 1: Summary of site report topic reviews (numbers)

	Number of Reports	Water Chemistry	Sediment Chemistry	Toxicity	Benthos	Zoo-plankton	Phyto-plankton	Macro-phytes	Fish - Tissue Residue	Fish - Population/ Community
Yukon Territory										
Sa Dena Hes (Mt. Hundere)	6	6	3	4	4	X	X	X	3	
Minto	2	1	X	X	1	X	X	X	X	1
Mount Nansen	1	1	X	X	1	X	X	X	X	1
United Keno Hill Mine	2	2	1	1	2	X	X	X	X	1
Venus Mine	2	2	1	X	1	X	X	X	1	X
MacMillan Pass Area	4	3	3	X	2	X	X	X	X	X
Cyprus Anvil Mine	3	1	X	1	2	X	X	X	X	X
Iona Silver Mine	1	1	X	X	X	X	X	X	X	X
Marbaco	1	X	X	X	1	X	X	X	X	X
Arctic Gold and Silver Mines	1	X	X	X	1	X	X	X	X	X
Various Hard Rock Mines	1	X	1	X	X	X	X	X	X	X
British Columbia										
Westmin, Myra Falls	8	5	2	X	X	1	1	X	2	X
Mt. Washington	2	2	X	X	1	X	X	X	X	X
Endako Mine	3	2	X	X	2	X	1	X	X	X
Hallmark Resources	1	1	X	X	1	X	X	X	X	X
Equity Silver	8	6	2	1	4	X	3	2	1	3
Bell Mine, Babine Lake	2	2	2	1	2	1	1	X	1	1
Baker Mine, Finlay Basin	1	1	X	X	X	X	X	X	X	X
Premier Gold	3	1	X	2	X	X	X	X	X	X
Mosquito Creek Mine	1	1	X	X	X	X	X	X	X	X
Cariboo Quartz Gold Mine	2	1	1	1	X	X	X	X	1	X
Brenda Mines	5	1	2	X	3	X	1	X	1	2
Nickel Plate Mine	2	1	X	X	1	X	X	X	X	X
Northair Mine (Brandywine)	1	X	X	X	1	X	X	X	X	X
Cominco, Trail Smelter	4	X	X	3	1	X	X	1	X	X
TOTAL	**67**	**41**	**18**	**14**	**31**	**2**	**7**	**3**	**10**	**9**

Table 1: Summary of site report topic reviews (numbers)(continued)

	Number of Reports	Water Chemistry	Sediment Chemistry	Toxicity	Benthos	Zoo-plankton	Phyto-plankton	Macro-phytes	Fish - Tissue Residue	Fish - Population/ Community
Reports reviewed but not included in strict terms of reference										
Silver Tusk Area	1	X	X	X	1	X	X	X	X	X
Howard's Pass Area	1	1	1	X	1	X	X	X	1	X
Yukon Territory (area study - Hg)	1	1	1	X	X	X	X	X	1	X
Yukon Placer Mines (General)	4	1	X	1	X	X	X	X	X	3
Barlow Creek (placer mine)	1	1	1	X	1	X	X	X	X	X
Hunker Creek (placer mine)	1	X	1	X	X	X	X	X	X	X
Little Gold Creek (placer mine)	1	X	X	X	1	X	X	X	X	X
Cinola Gold Mine Project	5	3	2	X	X	X	X	X	1	X
Windy Craggy Project	1	X	X	X	X	X	X	X	X	X
Quinsam Coal	1	X	X	X	X	X	1	X	X	X
Fording Coal Mine	4	2	1	X	X	X	1	X	X	X
Liard River Study (BC Hydro)	1	1	1	X	X	X	X	X	1	X
West Coast, Vancouver Is.	1	X	X	X	X	X	X	X	1	X
Thompson River	1	X	X	X	X	X	X	X	1	X
General/Lab./Lit. Review	3	X	1	2	X	X	X	X	X	X
TOTAL	**27**	**10**	**9**	**3**	**4**	**X**	**2**	**X**	**6**	**3**
TOTAL (all reviews)	**94**	**51**	**27**	**17**	**35**	**2**	**9**	**3**	**16**	**12**

Working Group 6 Comments on the Reviews and Review Process

1. Working Group 6 members reviewed those documents selected for WG6 by the AQUAMIN Secretariat. It was not within the terms of reference of WG6 to conduct a literature survey as a starting point for the review process. Furthermore, a literature survey would have revealed only those documents in the public domain. Within the terms of reference were the Responsibilities to:

   - review the site specific data and reports to determine the extent and significance of effects of metal mining on aquatic ecosystems
   - seek additional site information as required to understand local site specific features, characteristics, history, etc.

   Of the 66 reviewed documents that meet the AQUAMIN terms of reference (Table 1), the sources were:

Source	Documents	Percent of Documents
Federal Government	30	45
Provincial/Territorial Government	13	20
Formal Publications	4	6
Mining Companies (MAC*)	19	29
Total within TOR	66	100

*Mining Association of Canada Member Companies

   It is recognized by WG6 that these documents are far from a complete literature base for the evaluation of the MMLER in British Columbia and Yukon. Therefore, the documents reviewed were those in the AQUAMIN database. Further information was sought for the case studies.

2. Working Group 6 recognizes that none of the documents submitted for review were written for the purposes of AQUAMIN. It was not the intention of WG6 reviewers to criticize the authors of the documents, particularly as some of the documents report studies which were conducted up to twenty years ago. Any stated criticism is intended to be objective and relative only to the requirements of AQUAMIN.

3. AQUAMIN is concerned with the *Metal Mining Liquid Effluent Regulations* (MMLER) and, as such, is not intended to review other regulations whether Provincial, Territorial, or local. Nevertheless, the documents reviewed do contain references to water-quality

criteria other than those specified in the MMLER. Such references include guidelines, recommendations, and regulations promulgated by Federal, Provincial, Territorial, and local government agencies; thus, the references are reported in the reviews to give a historical perspective to the philosophy of water-quality monitoring, practice, and interpretation, and to give a frame of reference to the MMLER.

4. Although many water-quality and sediment-quality results were reported in the documents reviewed, information on water and sediment quantity was sparse. In general, the more recent studies included some water-flow rates, whereas the older studies did not. Unfortunately, as many of the most recent documents containing information on water quantity are concerned with exploration sites and proposed mines, they are listed in the second section of Table 1 as not meeting the AQUAMIN terms of reference for site review. Even where flow rates are reported, in only a few cases was the temporal sampling frequency adequate to assess the variation in seasonal flows.

Appendix 3: Background Levels of Metals in Bivalve Tissue

Bivalves have received extensive attention in the literature because of their reported ability to reflect environmental levels of trace metal. Mussels may exhibit different time-integration capacities for various elements, according to the cellular mechanisms involved in their detoxification and/or excretion. In the soft tissues, the highest concentrations are normally in the gut and digestive gland, with moderate amounts in mantle, gills, and gonads and lowest in muscle.

In the Goldberg model, the equation is:

$$dM/dt = KM_{sw}W - TM$$

where M = metal concentration in tissue
t = Age of organism
K = Constant
T = Biological half-life of metal
M_{sw} = Concentration of metal in seawater.

The process, however, is influenced by a number of biotic and abiotic factors. Under field conditions, the baseline level of the trace metals may vary tremendously depending upon the geochemistry of the sediment, season of sample collection, deviation from linearity for the uptake constant, and the pulses in M_{SW} due to variation discharge rate and composition, etc. Again, the age dependent metal concentrations may become blurred if data from different locations are pooled.

Baseline levels of these metals are hard to determine since they are very often influenced by a) the geochemistry of the local area from where the samples have been collected, b) genetic variability, c) the season of sample collection, d) the reproductive status, the age of the animals, etc. Values (µg/g dry whole body soft tissue) are for clean areas unless specified. The present day trend is to report tissue specific analysis.

Arsenic is one of only two elements which is biomagnified and is cause for concern. Near an As input: 5.3, and offshore: 1.6 (Penrose *et al.* 1975).

Copper and zinc are both essential trace elements. Certain regulation capabilities of these essential trace elements cannot be excluded as suggested for other mytelids, though exceptions have been noted. At least 50% of these elements are in the intracellular pool and

bound to many proteins (including high molecular weight proteins) and metallothioneins that regulate the intracellular metabolism of these metals involved in a wide variety of function such as activation of metalloenzymes, transport of oxygen and redox activities. On the other hand, lysosomes are involved in the catabolism of these proteins as well as in the detoxification processes of these metals. Association of copper and zinc with lysosomes and lysosome like inclusions and their major role in the metabolism and excretion of these metals have been demonstrated. Concentration is inversely correlated with size and tissue weight (Boyden 1974 and 1977; Cossa 1980), i.e., smallest animals contain the highest concentrations.

i) Australia- Copper: 3.0-4.8; zinc: 124-282 (Richardson *et al.* 1994).

ii) Gulf of St. Lawrence - Copper: 0.03-5.0 (approx.); zinc: 1.0-100.0 (approx.) (Cossa *et al.* 1980)

iii) Poole, U.K. - Copper: 1.5-16 (approx.); zinc: 5-250 (approx.) (Boyden 1977); please note the values are for total content and not concentrations, total dry tissue weight varied from 0.05 to 2.5 g).

iv) U.S. Mussel Watch (West Coast) - Copper: 3.5-8.6; zinc: 90.0-260.0 (Goldberg et al. 1978). U.S. Mussel Watch (East Coast) - Copper: 6.7-13.2; zinc: 67.0-189.0 (Goldberg *et al.* 1978).

Lead concentrations are extremely variable as seen in the following examples.

i) Halifax Inlet - 1.9- 12.1 (Ward 1990).

ii) U.S. Mussel Watch (West Coast) - 1.9-8.8 (Goldberg *et al.* 1978).

iii) U.S. Mussel Watch (East Coast) - <0.4-9.5 (Goldberg *et al.* 1978).

Nickel

i) Gulf of St. Lawrence - 0.05 - 2.0 (approx.) (Cossa *et al.* 1980).

ii) U.S. Mussel Watch - 0.4 - 6.3 (Goldberg *et al.* 1978).

References

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Appendix 4: Supplementary Comments from Alan Penn on Regional Synthesis for Eastern Canadian Shield - Quebec

The following notes and observations were supplied by Mr. Alan Penn (Cree Regional Authority), a member of the Québec sub-group.

1 The Selection of the Case Studies

Some additional comments may help place the case studies in regional and historical perspective. The Aldermac mine (which produced ore - mainly copper - at about 1000 t.p.d., between 1932 and 1943), is one of about 20 mines in the Noranda district of the Abitibi belt in the Superior Province. It is located some 15 km West of the Rouyn-Noranda smelting and refining complex. Base metal mining has declined in the region, but smelting at Noranda attracted considerable attention in the course of the debate over the reduction of sulfur dioxide emissions. The Noranda region has experienced not only the consequences of the mining of metal sulphides but the deposition of both acidity and heavy metals from the associated smelting. The long history of both base metal mining and of smelting in this areas makes it difficult, and perhaps impossible, to disentangle the effects of the two sources of metal contamination. The paucity of background ecological data in this geologically heterogeneous region poses additional difficulties.

The Matagami case study, also, involves a complex history of land use. A total of nine distinct mines (copper/zinc) have been operating since 1963, and the last of the operations is scheduled to close in 1997, after the extraction of some 45 million tonnes of ore. The ore was milled at two central concentrators and deposited in a lake (Watson Lake) which was, in effect, converted into a tailings pond. Clays and silts of glacial lake Barlow-Ojibway, and associated muskeg formations, play an important role in the local hydrology and limnology. Terrain disturbance associated with commercial forestry and road construction have further complicated the picture. Finally, Lake Matagami lies downstream from a major pulp and paper complex (Quévillon), the site of major losses of metallic mercury in the period from 1968 to 1977. The investigation used in the AQUAMIN review was designed to provide background information for use in the preparation of close-out plans now required under Québec's legislation governing mining operations.

The other case study involves the Gaspé copper mines (Copper Mountain and Needle Mountain), from which approximately 40 million tonnes of ore have been mined over a forty

year period. This is a case where pyrrhotite and chalcopyrite are mined in metamorphosed argillaceous limestone or calcareous shales. In addition to copper, Au, Ag, Mo, Bi and Se are also recovered. Mining is located in the headwaters of a salmon river (York River); although the regional geology provides ample buffering against acid drainage, it was an accident involving the spilling of sulphuric acid (and the subsequent use of lime to counter its effects) that resulted in the collection of some of the ecological data used in the case study, which also notes several previous releases of tailings from mineral processing operations.

None of these three situations is particularly appropriate for assessing the effectiveness of the *Metal Mining Liquid Effluent Regulations*. Quite apart from regulatory issues, the complex history of mining (and other industrial activities) in these locations is not conducive to an evaluation of the relationship between effluent (or sediment) composition, mine operation, and stream or lake biota.

2 Québec's Regulatory Regime and the MMLER

The sub-group report refers to Directive 019 as the instrument used in Québec to control the effluent from mining operations. Some further clarification may be helpful. This is an administrative directive, adopted in 1989 for the application of article 22 of Québec's Environment Quality Act. Using this article, Québec's Ministère de l'Environnement et de la Faune issues certificates of authorisation for mining operations. These authorizations refer to the plans and specifications of the industrial activity in question, and do not include terms and conditions of authorisation. The company, nevertheless, is asked to comply with Directive 019. The law, therefore, does not provide for site-specific conditions of initial approval, and there is no system of operating licences (and therefore limited scope for periodic review of conditions of operation or environmental performance).

Directive 019 incorporates many of the provisions of the *Metal Mining Liquid Effluent Regulations*, and adds others (notably for total and w.a.d. cyanide). In effect, it consolidates and standardises the obligations of the mining industry with respect to the definition of the physical and chemical characteristics of both the aquatic and sedimentary environment of the mining operation within the framework of a provincial statute; and it introduces as well the notion of critical discharge - the calculation of acceptable dilution factors for mining effluent in order to achieve certain water quality criteria in the receiving environment.

This in effect implies the reassessment of the MMLER in Quebec, necessarily involves an assessment of the Directive 019. This policy directive, adopted 12 years after the MMLER, filled a gap at a provincial level and it also has significant implications for the review of the MMLER and the possibility of evaluating their ecological relevance. This directive, like the MMLER, is rooted in the concept of best practical technology (i.e. achievable using a tailings

pond and the addition of reagents for pH control); it is not designed to satisfy particular ecological objectives, and there is little room for adaptation to local conditions. The sampling and analytical requirements are quite general, and reporting is limited. This makes it difficult to interpret, and therefore, use the data so generated. The question of confidentiality also remains central. The diverse sampling and analytical problems associated with assessing the bioavailability of metals only adds to the problem.

3 Implications for Environmental Effects Monitoring.

The review of the available data made it clear that we are a long way from being in a position to link effluent or sediment composition with biological indicators; and that the goal of being able to link performance with ecological effects (which appears to be a necessary pre-condition for the constructive review of MMLER) is even more remote.

This rather unsatisfactory situation will raise questions both about the relevance of the MMLER and the counter-part Québec directive. A more coherent relationship between regulatory policy and the design and operation of mines and mineral processing facilities will require some understanding of ecological effects. In this sense, ecological effects monitoring (EEM) is clearly a desirable policy objective, whether voluntary or regulated. This appears to be a prerequisite for optimizing mining operations in order to take into account well-defined ecological objectives.

The kind of questions that can be addressed depends very much on the individual mine (the suite of metals and associated mineralogy) as well as the local hydrology and limnology. There is no reason to expect uniformity, and very strong arguments can be made for a site specific-approach to ecological monitoring. In some cases, perhaps illustrated by the case studies themselves, the situation may be so confused by past disturbance that environmental effects monitoring may be of limited value.

Precisely because so many mines are opened in areas of previous or concurrent mining activity (for very good geological reasons), some form of across-industry cooperation - not to mention coordination between federal and provincial agencies - seems essential if EEM is to serve a useful purpose.

But there is also a pressing need for consensus about the kind of effects being sought and the significance that will be ascribed to them. It is certainly important that far more emphasis be placed on experimental design in planning sampling programmes; and it would be a very positive step if target levels of statistical power and detectable effect size were explicitly reviewed in planning such surveys. This would be refreshing move; but it would not eliminate the need for consensus about the kind of effects that are to be sought, or about the selection

of the sites most likely to yield useful information about the impacts of specific mining effluents.

It is possible, and even probable, that a mining company may find itself targeting operations in a particularly vulnerable ecological setting. From the perspective in which EEM is being used to improve our understanding of the relations between mining and ecological effects, it may be an ideal situation. However, the fact that the ecological effects are relatively easy to document at that location may mean that the company would feel that it is being selectively penalised by the EEM policy. It would be particularly important to avoid siutations in which the company withdraws its willingness to collaborate in the EEM program. The company's reluctance to remain involved, because of the ecological characteristics of its mine site, may compromise the objectives of the EEM program as a whole. This potential situation should be taken into account when planning working relationships with mining companies in the framework of the implementation of an EEM strategy.